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Age-Specific Normative Values for CT Exophthalmometry in Adult Women from Jiangxi, China: Associations with Smoking, BMI, and Skeletal Frame—A Cross-Sectional Study

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Age-Specific Normative Values for CT Exophthalmometry in Adult Women from Jiangxi, China: Associations with Smoking, BMI, and Skeletal Frame—A Cross-Sectional Study

Abstract

Objective: To establish age-specific normative reference values for CT exophthalmometry applicable to Chinese adult women, and to assess their associations with smoking and anthropometric characteristics.

Methods: This cross-sectional study analyzed 1,607 adult females from Jiangxi Province who underwent 1-mm slice orbital CT scans with multiplanar reconstruction. Exophthalmos and interorbital distance were measured via CT. Data on age, smoking status, BMI, and body frame index (derived from the ratio of height to wrist circumference) were collected. Multivariable linear regression was performed to adjust for confounders.

Results: Age-stratified reference values were established. Right-eye exophthalmos was 14.81±1.89 mm (≤40y), 14.95±1.88 mm (41–60y), 14.77±1.96 mm (61–80y), and 14.16±2.29 mm (≥81y); left-eye values were 14.78±1.94 mm, 15.02±1.86 mm, 14.83±1.99 mm, and 14.24±2.15 mm, respectively. The 41–60y group had significantly higher values than the ≥81y group (right: P=0.018; left: P=0.020). Multivariable analysis revealed that smoking was independently associated with greater right-eye exophthalmos (β=3.01 mm, 95% CI: 2.22–3.80, P<0.001), left-eye exophthalmos (β=2.76 mm, 95% CI: 1.96–3.55, P<0.001), and interorbital distance (β=3.00 mm, 95% CI: 1.72–4.28, P<0.001). Larger body frame was also independently associated with greater right-eye exophthalmos (large vs. small frame difference: 3.15 mm, 95% CI: 2.62–3.69, P<0.001). Higher BMI was associated with increased exophthalmos (Normal weight vs. Overweight, P<0.001).

Conclusion: Exophthalmos in Chinese adult women exhibits age-specific differences. Smoking, elevated BMI, and larger body frame are independently associated with increased orbital prominence and interorbital distance. These CT-based age-specific values provide a more suitable reference for Chinese women than existing European standards.

Keywords: Exophthalmometry; Orbital Computed Tomography; Normative values; Smoking; Body Mass Index

1. Background

Exophthalmometry is a crucial clinical indicator for evaluating orbital diseases such as thyroid eye disease (TED), orbital tumors, and orbital fractures. It is defined as the perpendicular distance from the corneal apex to the line connecting the most anterior points of the bilateral zygomatic arches. Accurate measurement is vital for diagnosis, treatment planning, and efficacy assessment. Although the Hertel exophthalmometer remains the primary clinical tool, its results are highly susceptible to technical and physiological factors. Variations in footplate placement, applied pressure, and facial asymmetry can alter the reference plane, leading to intra- and inter-examiner errors of 1–2 mm[1]. Therefore, establishing precise measurement techniques and localized normative reference values is the cornerstone of accurate clinical interpretation.

With the advancement of imaging technology, computed tomography (CT)[2, 3] has become the gold standard for orbital imaging and precise exophthalmometry measurement[4, 5]. Its superb bone resolution clearly displays anatomical details of orbital walls, optic canals, and periorbital sinuses. This is crucial for assessing trauma, diagnosing bony tumors (e.g., intraosseous hemangioma[6]), and craniofacial malformations (e.g., Pfeiffer syndrome[7]). In TED, CT accurately demonstrates spindle-shaped extraocular muscle enlargement with tendon sparing[8]. However, conventional axial CT images have inherent limitations in providing intuitive, three-dimensional representations of the orbit. Multiplanar reconstruction (MPR), a core post-processing technique, compensates for this by generating coronal, sagittal, and oblique images, significantly aiding preoperative planning and functional reconstruction[9].

Exophthalmometry values are significantly influenced by ethnicity and geographical region. Individuals of African descent exhibit the highest values (approximately 17.5–18.2 mm)[10]. Caucasian populations fall in the medium-to-high range (approximately 16.5–17.8 mm)[11, 12], with Lithuanian children/adolescents averaging 16.6–17.6 mm[13]. Asian populations generally have lower exophthalmometry, with variations among subgroups. East Asians (e.g., Koreans) average approximately 14.8–15.6 mm[14]. South Asians (e.g., South India) average about 14.7 ± 1.70 mm[15], while West Asians (e.g., Iranians) average about 16.3 mm in adults[16] (Table 1). Due to ethnic differences and inconsistent measurement standards, these data may not fully apply to specific Chinese subpopulations. Currently, CT-measured normative exophthalmometry data for healthy adult women in Jiangxi Province remains scarce, hindering precise orbital disease assessment for this demographic.

While thyroid dysfunction is the primary etiological factor for proptosis, clinical changes in exophthalmometry in many patients cannot be fully explained by known thyroid pathology or typical orbital diseases (such as tumors[17], inflammation[18, 19], and trauma[20, 21]. This suggests the influence of other systemic or constitutional factors. Among them, smoking status has attracted widespread attention. Substantial research confirms that smoking is not only a significant risk factor for TED but also aggravates its severity and reduces treatment responsiveness[22-24]. Tobacco-induced oxidative stress may exacerbate autoimmune inflammation and fibrosis in orbital tissues[25]. Theoretically, in normal populations, smoking could subtly affect intraorbital fat volume or orbital septum tension, altering the relative position of the eyeball.

Furthermore, Body Mass Index (BMI) and its relationship with craniofacial morphology have become a research hotspot. A cross-sectional study demonstrated significant associations between BMI and various facial anthropometric parameters [26]. An MRI-based volumetric study further found a positive correlation between intraorbital fat volume and BMI[27], suggesting that increased BMI may push the eyeball forward by increasing orbital content volume. Additionally, the skeletal frame, which is not purely reflected by BMI, may play a role. Public perception of a "normal" body shape may be influenced by skeletal robustness, not just fat content[1]. Biomechanically, a larger Body Frame Index (BFI) implies a broader bony orbital volume, potentially allowing the eyeball to occupy a relatively more posterior position (the "container effect"). However, research on the relationship between BFI and exophthalmometry is scarce. Insights from a cohort study on Brazilian older adults suggest that the association between BFI—determined by genetics and early development—and exophthalmometry might represent a stable relationship persisting throughout the lifecycle, making it suitable for investigation in adult cohorts[28].

In summary, normal variations in exophthalmometry may be associated with smoking, BMI, and skeletal frame. This study aims to establish age-specific normative reference values for CT exophthalmometry in adult women from Jiangxi Province, and to assess their associations with smoking, BMI, and body frame index. These findings may provide a more suitable localized reference for clinical practice and identify modifiable risk factors beyond the traditional thyroid disease pathway.

2. Methods

2.1 Inclusion and Exclusion Criteria

We included healthy adult women from Jiangxi Province who underwent orbital CT examinations at our hospital between January 1, 2021, and December 31, 2025. Inclusion criteria were: (1) females aged ≥18 years; (2) completed standardized orbital CT scans; and (3) no diseases affecting exophthalmometry.

Exclusion criteria were: (1) conditions affecting exophthalmometry, including thyroid eye disease, orbital tumors, inflammatory lesions, fractures, or orbital rim defects; (2) high myopia (spherical equivalent ≤ -6.00 diopters or axial length ≥ 26.0 mm) causing pseudoproptosis; (3) non-standard CT positioning; and (4) cognitive impairment or significant recall bias regarding smoking history.

The study ultimately comprised 321 adults with complete data. Data recorded included age, height, weight, smoking status, and wrist circumference. The study was approved by the Ethics Committee of the Eye Hospital of Nanchang University and conformed to the Declaration of Helsinki.

2.2 Measurement of Exophthalmometry by Orbital CT Method

Exophthalmometry was measured using orbital CT with multiplanar reconstruction (MPR). The reference plane was defined as the line connecting the most anterior points of the bilateral lateral orbital walls (interorbital line) at the level of the frontozygomatic suture. On axial images, a perpendicular line was drawn through this plane, and the distance from the corneal apex to this line defined the exophthalmometry value (mm) for each eye [29]（(Figure 1), This technique uses stable bony landmarks, minimizing errors from head mispositioning.

All scans were performed with subjects supine, eyes closed, and the head in a neutral position (orbitomeatal line perpendicular to the scanner table). A single radiologist operated a SOMATOM PLUS 4 POWER CT scanner using continuous 1-mm slice thickness orbital tomography[2]. DICOM files were imported into RadiAnt DICOM Viewer 2021.2. In the MPR view, the imaging plane was

aligned to the medial/lateral rectus muscles and optic nerve, using the bilateral lateral orbital rims as the baseline. Perpendicular lines were drawn from the anterior apex of each globe to the baseline.

To ensure reliability, scans extended from the frontal sinus superior border to the hard palate inferior border. Imaging parameters balanced quality and radiation dose[30]. The clearest slice at the lens center level was selected. For patients with facial asymmetry or prior orbital surgery, reference lines were established individually per side to avoid errors from unequal bilateral orbital rim positions..

2.3 Statistical Analysis

Statistical analyses were performed using Python 3.12. Normality was assessed using the Shapiro-Wilk test. Normally distributed continuous data are presented as mean ± standard deviation ($\bar{x} \pm s$), while skewed data are presented as median (interquartile range) [M (Q1, Q3)]. Categorical data are presented as counts and percentages.

For inter-group comparisons, homogeneity of variances was assessed using Levene's test. One-way ANOVA or the Kruskal-Wallis test was applied based on data distribution. Post-hoc pairwise comparisons used Tukey's HSD test or the Bonferroni-corrected Mann-Whitney U test. The 95% reference ranges were calculated using $\bar{x} \pm 1.96s$ for normally distributed data, and the 2.5th to 97.5th percentiles for skewed data. Right and left eye differences were compared using paired t-tests or the Wilcoxon signed-rank test, and their absolute differences were calculated.

Subjects were grouped by age (≤40, 41–60, 61–80, ≥81 years), BMI (Underweight <18.5, Normal 18.5–<24.0, Overweight 24.0–<28.0, Obesity ≥28.0 kg/m²), smoking status (current smokers with ≥1 cigarette/day for ≥6 months or ≥100 cumulative cigarettes vs. non-smokers/former smokers ≥1 year)[31, 32]. and Body Frame Index (BFI = height/wrist circumference; Small, Medium, Large frame).

Given baseline imbalances (gender in smoking groups; age and gender in body frame groups), multiple linear regression models were used to estimate adjusted mean differences and 95% confidence intervals (CIs), with $P < 0.05$ considered statistically significant. Adjusted marginal means were plotted

in bar charts with 95% CIs. Box plots and histograms with scaled kernel density curves were generated to visualize distributions and 95% reference boundaries.

3. Results

3.1 Age Group Comparison

A total of 1607 subjects were included in this study and categorized into four age groups: ≤40 years (n=218), 41–60 years (n=804), 61–80 years (n=531), and ≥81 years (n=54). The descriptive statistics for right-eye exophthalmometry, left-eye exophthalmometry, and interorbital distance for each group are presented in Table 2. All measurements were normally distributed within each age group (Shapiro-Wilk test, all $P > 0.05$). Therefore, they are described as mean ± standard deviation ($\bar{x}\pm s$), and the 95% reference ranges were calculated using the method for normal distribution ($\bar{x} \pm 1.96s$).

The right-eye exophthalmometry values for the ≤40, 41–60, 61–80, and ≥81 years groups were 14.81±1.89 mm, 14.95±1.88 mm, 14.77±1.96 mm, and 14.16±2.29 mm, respectively. The corresponding left-eye exophthalmometry values were 14.78±1.94 mm, 15.02±1.86 mm, 14.83±1.99 mm, and 14.24±2.15 mm. The interorbital distances were 94.50±3.31 mm, 94.21±3.26 mm, 94.39±3.18 mm, and 95.23±3.50 mm, respectively.

Homogeneity of variances tests indicated that the variances for all indicators were equal across the different age groups (Levene's test, all $P > 0.05$). One-way analysis of variance showed that the differences in right-eye exophthalmometry ($F=3.436$, $P=0.016$) and left-eye exophthalmometry ($F=3.725$, $P=0.011$) among the different age groups were statistically significant, while the difference in interorbital distance was not statistically significant ($F=2.027$, $P=0.108$). Further pairwise comparisons using Tukey's HSD method revealed that the right-eye exophthalmometry in the 41–60 years group was significantly higher than that in the ≥81 years group (difference 0.79 mm, $P=0.018$). Similarly, the left-eye exophthalmometry in the 41–60 years group was significantly higher than that in the ≥81 years group (difference 0.78 mm, $P=0.020$). All other pairwise comparisons between age groups showed no statistically significant differences (all $P > 0.05$). The distributions of right-eye

exophthalmometry, left-eye exophthalmometry, and interorbital distance for each age group are shown in Figures 2 to 3.

Within each age group, paired comparisons of exophthalmometry between the right and left eyes were conducted (Table 3). The difference in exophthalmometry between the right and left eyes in the 41–60 years group was statistically significant (Wilcoxon signed-rank test, P=0.002), with the left eye showing slightly higher exophthalmometry than the right eye (median difference of 0). No statistically significant differences were found between the right and left eyes in the other age groups (all $P > 0.05$).

The absolute difference in exophthalmometry between the right and left eyes (|Right - Left|) was calculated within each age group. Their distributions were all skewed (Shapiro-Wilk test, all $P < 0.001$). Therefore, they are described using the median (interquartile range, IQR), and the 95% reference ranges were determined using the percentile method . The absolute difference was 0.44 (0.19–0.82) mm [95% reference range: 0–1.66 mm] for the ≤40 years group; 0.43 (0.16–0.81) mm [95% reference range: 0–1.67 mm] for the 41–60 years group; 0.42 (0.13–0.78) mm [95% reference range: 0–1.62 mm] for the 61–80 years group; and 0.44 (0.29–0.81) mm [95% reference range: 0–1.60 mm] for the ≥81 years group. Histograms showing the distribution of the absolute differences for each age group are presented in Figures 4.

The 95% reference ranges for bilateral exophthalmometry in adult women across different age groups are shown in Figure 5:

3.2 BMI Group Comparison

According to the Chinese adult BMI classification criteria, the study subjects were divided into four groups: Underweight (<18.5 kg/m², n=4), Normal weight (18.5～<24 kg/m², n=184), Overweight (24～<28 kg/m², n=108), and Obesity (≥28 kg/m², n=19). Analysis of baseline characteristics showed no statistically significant differences in age (Kruskal-Wallis test, P=0.514) or gender distribution (χ^2=3.769, P=0.288) among the groups, indicating they were comparable.

Descriptive statistics for right-eye exophthalmometry, left-eye exophthalmometry, and interorbital distance for each group are presented in Table 4. As the data for some groups did not meet

the normality assumption, the Kruskal-Wallis test was used for inter-group comparisons (interorbital distance met the assumptions of normality and homogeneity of variances, thus ANOVA was used). The results showed statistically significant differences in right-eye exophthalmometry ($H=25.79$, $P<0.001$), left-eye exophthalmometry ($H=27.53$, $P<0.001$), and interorbital distance ($F=3.115$, $P=0.026$) among the different BMI groups.

The results of pairwise comparisons (Table 5) showed:

Right-eye exophthalmometry: The Normal weight group was significantly lower than the Overweight group (Bonferroni-corrected $P<0.001$). No other inter-group comparisons showed statistically significant differences (all corrected $P>0.05$).

Left-eye exophthalmometry: The Normal weight group was significantly lower than the Obesity group (corrected $P=0.017$) and the Overweight group (corrected $P<0.001$). The Obesity group was significantly higher than the Underweight group (corrected $P=0.050$).

Interorbital distance: The Normal weight group was significantly lower than the Overweight group (Tukey's HSD, $P=0.018$). No other inter-group differences were statistically significant (all $P>0.05$).

Box plots of right-eye exophthalmometry, left-eye exophthalmometry, and interorbital distance according to BMI groups are shown in Figures 6-7.

3.3 Smoking Group Comparison

Based on smoking history, subjects were divided into a non-smoker group (n=286) and a smoker group (n=30). Baseline comparison showed no statistically significant difference in age between the two groups (Kruskal-Wallis test, $P=0.187$), but a significant difference in gender distribution ($\chi^2=25.38$, $P<0.001$), with a higher proportion of males in the smoker group .

Descriptive statistics are shown in Table 6. Neither right-eye exophthalmometry (non-smoker group: 14.33±1.96 mm, smoker group: 17.28±2.32 mm) nor left-eye exophthalmometry (non-smoker group: 14.37±1.96 mm, smoker group: 17.06±2.39 mm) met the normality assumption. The Kruskal-

Wallis test showed that the smoker group had significantly higher values than the non-smoker group for both right-eye (H=38.95, P<0.001) and left-eye exophthalmometry (H=31.83, P<0.001). Interorbital distance met the assumptions of normality and homogeneity of variances, and the smoker group (98.27±3.12 mm) also had a significantly greater interorbital distance than the non-smoker group (94.35±3.37 mm), ANOVA F=37.28, P<0.001. Pairwise comparisons (only two groups) all indicated that the smoker group had significantly higher values for all measured indicators (all P<0.001). Box plots for the smoking groups are shown in Figures 8-9.

Since the gender distribution was imbalanced between the smoking and non-smoking groups, multiple linear regression was employed to adjust for gender (and age, although age showed no significant difference). After adjustment, the smoker group still exhibited 3.01 mm higher right-eye exophthalmometry (95% CI: 2.22 to 3.80, P<0.001), 2.76 mm higher left-eye exophthalmometry (95% CI: 1.96 to 3.55, P<0.001), and 3.00 mm greater interorbital distance (95% CI: 1.72 to 4.28, P<0.001) compared to the non-smoker group . Bar charts of the adjusted marginal means (Figures 10-11) show that all measured indicators in the smoker group remained significantly higher than those in the non-smoker group after adjusting for gender.

3.4 Body Frame Group Comparison

Based on the ratio of height to wrist circumference (Body Frame Index) combined with gender, the study subjects were divided into three groups: small frame (n=61), medium frame (n=81), and large frame (n=174). Analysis of baseline characteristics revealed significant differences among the groups in both age (Kruskal-Wallis test, P=0.001) and gender distribution (χ^2=13.53, P=0.001). The large frame group was younger and had a higher proportion of males.

The descriptive statistics for right-eye exophthalmometry, left-eye exophthalmometry, and interorbital distance for each group are presented in Table 7. The Kruskal-Wallis test was used for right-eye and left-eye exophthalmometry, and ANOVA was used for interorbital distance. The results showed statistically significant differences in all indicators among the three groups (right-eye: H=134.16, P<0.001; left-eye: H=130.92, P<0.001; interorbital distance: F=5.627, P=0.004).

The results of pairwise comparisons (Table 8) showed:

Right-eye exophthalmometry: The large frame group (15.71±1.81 mm) was significantly higher than the medium frame group (13.73±1.31 mm, P<0.001) and the small frame group (12.65±2.13 mm, P<0.001). The medium frame group was also significantly higher than the small frame group (P<0.001).

Left-eye exophthalmometry: Similarly, the pattern was large frame group (15.74±1.84 mm) > medium frame group (13.72±1.38 mm) > small frame group (12.67±1.84 mm), with all pairwise comparisons being statistically significant (all P<0.001).

Interorbital distance: The large frame group (95.28±3.43 mm) was significantly greater than the small frame group (93.66±3.79 mm, P=0.006). No other inter-group comparisons were statistically significant (all P>0.05).

Box plots for the body frame groups are shown in Figures 12-13.

Given the uneven distribution of age and gender among the body frame groups, multiple linear regression was employed to adjust for age and gender (Table 9). After adjustment, the large frame group still had significantly higher right-eye exophthalmometry than the small frame group (difference: 3.15 mm, 95% CI: 2.62 to 3.69, P<0.001) and the medium frame group (difference: 2.04 mm, 95% CI: 1.56 to 2.52, P<0.001). The medium frame group also had significantly higher right-eye exophthalmometry than the small frame group (difference: 1.11 mm, 95% CI: 0.52 to 1.71, P<0.001). Results for left-eye exophthalmometry were similar (large frame vs. small frame: 3.20 mm, 95% CI: 2.67 to 3.72; large frame vs. medium frame: 2.10 mm, 95% CI: 1.63 to 2.56; medium frame vs. small frame: 1.10 mm, 95% CI: 0.52 to 1.68; all P<0.001). Regarding interorbital distance, only the difference between the large and small frame groups remained statistically significant (difference: 1.24 mm, 95% CI: 0.24 to 2.25, P=0.015), while other comparisons were not statistically significant. Bar charts of the adjusted marginal means are shown in Figures 14, with statistically significant inter-group comparisons marked on the charts.

4. Discussion and Prospects

This study, for the first time, established age-specific normal reference ranges for exophthalmometry and interorbital distance in adult women from Jiangxi Province using CT

measurements, and systematically analyzed the influencing factors of smoking, body mass index, and body frame index. The results found that smoking was significantly associated with higher exophthalmometry and greater interorbital distance. Simultaneously, both BMI and the Body Frame Index showed positive associations with exophthalmometry and interorbital distance. These findings contribute to understanding the physiological variation in orbital structures within the normal population and its potential impact on clinical interpretation or misdiagnosis.

The primary strength of this study lies in the use of multiplanar reconstructed CT for precise measurements, which avoids the subjectivity of traditional clinical methods and errors caused by variations in lateral orbital rim positioning. Furthermore, we are the first to systematically quantify the independent effects of smoking, BMI, and body frame index on orbital parameters in a normal Chinese population. The particularly large effect size associated with smoking holds significant public health implications. However, this study also has several limitations. First, as a cross-sectional study, it cannot establish a causal relationship between smoking and exophthalmometry. Second, the study population is limited to adults from Jiangxi Province; therefore, caution is needed when generalizing the conclusions to other regions or ethnicities. Third, while smoking status was analyzed, the quantification of smoking exposure (e.g., pack-years) was not included, failing to reveal a dose-response relationship. Future research could incorporate more detailed smoking histories, thyroid antibody levels (such as TRAb, TPOAb)[33, 34], and precise volumetric measurements of intraorbital fat and muscles to gain deeper insights into the underlying mechanisms. For instance, in TRAb-negative TED patients, antibodies to thyroid peroxidase and thyroglobulin are also associated with specific clinical manifestations[34], suggesting that different autoimmune backgrounds may influence the orbit.

In terms of clinical significance, the normal reference values established in this study can provide a basis for clinical diagnosis in Jiangxi Province and similar populations. For ophthalmologists, endocrinologists, and plastic surgeons, when evaluating a patient's exophthalmometry, it is essential to routinely consider their smoking history, BMI, and body size for an individualized assessment[1]. Particularly for individuals presenting with mild proptosis and normal thyroid function, a detailed smoking history should be obtained and regarded as a modifiable risk factor. From a public health perspective, vigorously promoting smoking cessation is beneficial not only for preventing

cardiopulmonary diseases and TED[35, 36], but may also contribute to maintaining normal orbital anatomy. For individuals with a higher BMI, weight control is recommended to reduce various health risks, which may potentially include physiological exophthalmometry affecting orbital aesthetics.

Looking ahead, more large-scale, multicenter, prospective studies are needed to validate our findings and explore the underlying biological mechanisms. For example, research could investigate how smoking specifically affects the metabolism and volume of intraorbital fat. Animal model studies, such as adenovirus-induced TED mouse models exposed to cigarette smoke, have confirmed the role of the RAGE signaling pathway in smoking-induced exacerbation of disease progression[37]. It is worth exploring whether similar mechanisms operate under normal physiological conditions. Furthermore, with the advancement of artificial intelligence and radiomics, leveraging large annotated datasets (such as the TOM500 datase) to develop automated measurement and diagnostic tools will aid in the more efficient and accurate assessment of orbital parameters[38]. Integrating clinical variables (e.g., smoking, BMI) could further enhance diagnostic performance[39, 40]. The ultimate goal is to achieve stratified management and early intervention for orbital disease risks, thereby improving patients' quality of life.

5. Conclusion

This study, utilizing the orbital CT multiplanar reconstruction measurement method, established for the first time normal reference ranges for exophthalmometry and interorbital distance in adult women from Jiangxi Province, China, and systematically analyzed their influencing factors. The main conclusions are as follows:

Age-related differences exist in exophthalmometry among adult women in Jiangxi Province. The 41–60 years age group had the highest exophthalmometry, which was significantly lower in the ≥81 years group. The 95% reference range for the absolute difference in exophthalmometry between eyes was 0–1.67 mm, suggesting that an inter-eye difference >1.7 mm is more suitable as a threshold for judging pathological proptosis in this region. The overall mean exophthalmometry was significantly higher than traditional European standards, confirming the necessity of establishing localized normal values for the Chinese population.

BMI shows a positive association with exophthalmometry. Individuals who were overweight or obese had significantly higher exophthalmometry and interorbital distance compared to the normal weight group, suggesting that weight gain may lead to anterior displacement of the eyeball through increased intraorbital fat volume.

Smoking is an independent risk factor for exophthalmometry. After adjusting for gender and age, smokers still exhibited significantly higher exophthalmometry and interorbital distance than non-smokers, indicating that smoking can independently influence orbital anatomical parameters. This provides a basis for smoking cessation intervention from the perspective of orbital health.

Body Frame Index is a key determinant. After adjusting for confounding factors, the gradient relationship of large frame>medium frame>small frame remained stable, indicating that craniofacial skeletal development is a crucial innate factor determining the relative degree of exophthalmometry.

In summary, exophthalmometry is influenced by a combination of ethnicity, region, age, BMI, smoking, and body frame. Clinical assessment should utilize localized reference values and incorporate individual characteristics for comprehensive judgment. The findings of this study can provide an objective basis for orbital disease screening, assessment of thyroid-associated ophthalmopathy, and orbital surgical planning for populations in Jiangxi Province and those with similar genetic backgrounds.

Declarations

Contributions: (I) Conception and design: Ying Hu , Xinyu Li and Zhangjun Ren; (II) Administrative support: Hongfei Liao and Chao Xiong; (III) Provision of study materials or patients: Hongfei Liao, Chao Xiong; (IV) Collection and assembly of data: Gang Hu and Qi Jin; (V) Data analysis and interpretation: Gang Hu and Qi Jin; (VI) Manuscript writing and Final approval of manuscript: All authors.

Ethical Approval

The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This retrospective study was conducted in accordance with the Declaration of Helsinki. The requirement

for written informed consent was waived by the Ethics Committee of the Affiliated Eye Hospital of Nanchang University due to the retrospective nature of the study, which utilized fully anonymized data.

Consent for Publication

Not Applicable

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Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request. The original data have been anonymized to ensure patient confidentiality.

Conflict of Interests

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial in terest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing ar rangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

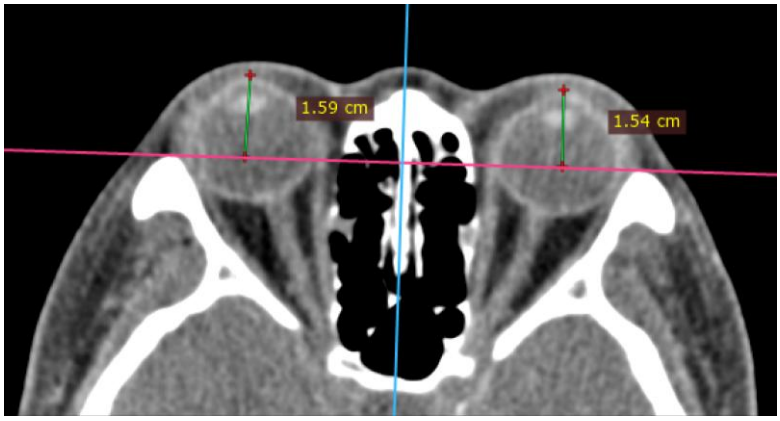


Figure 1 Schematic Diagram of Exophthalmometry Measurement Using Orbital CT.

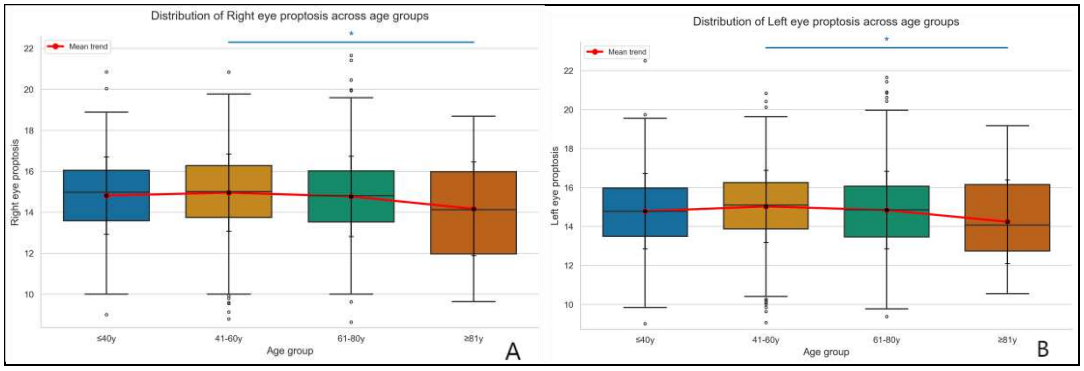


Figure 2 (A) Distribution of Right Exophthalmos Across Age Groups; (B) Distribution of Left Exophthalmos Across Age Groups.

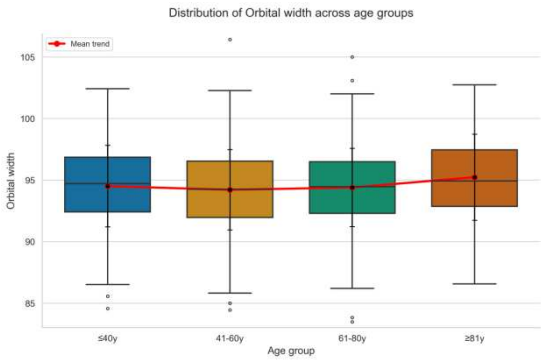


Figure 3 Distribution of Interorbital Distance Across Age Groups.

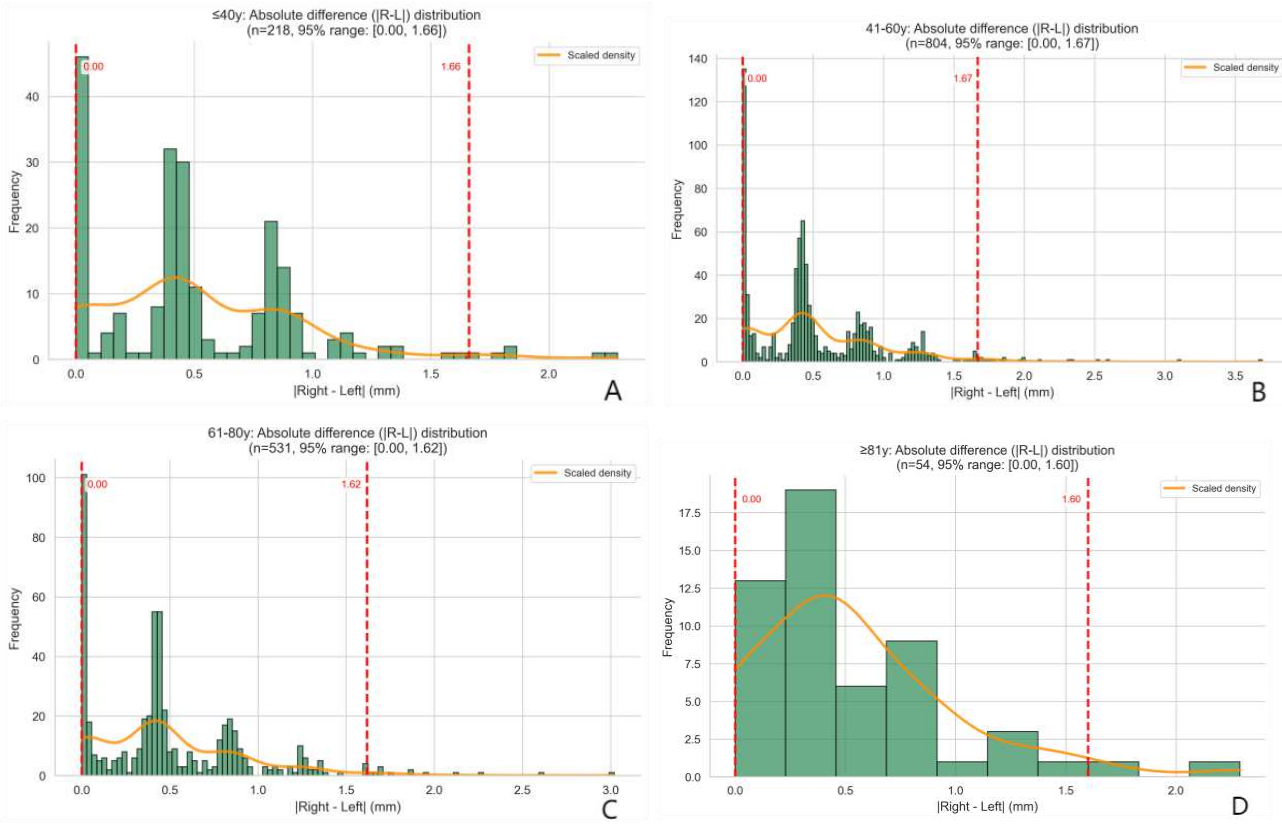


Figure 4 (A) Age ≤40 Years: Distribution of the Absolute Difference in Exophthalmos Between the Right and Left Eyes (n=218, 95% Range: [0.00, 1.66]); (B) Age 41-60 Years: Distribution of the Absolute Difference in Exophthalmos Between the Right and Left Eyes (n=804, 95% Range: [0.00, 1.67]); (C) Age 61-80 Years: Distribution of the Absolute Difference in Exophthalmos Between the Right and Left Eyes (n=531, 95% Range: [0.00, 1.62]); (D) Age ≥81 Years: Distribution of the Absolute Difference in Exophthalmos Between the Right and Left Eyes (n=54, 95% Range: [0.00, 1.60]).

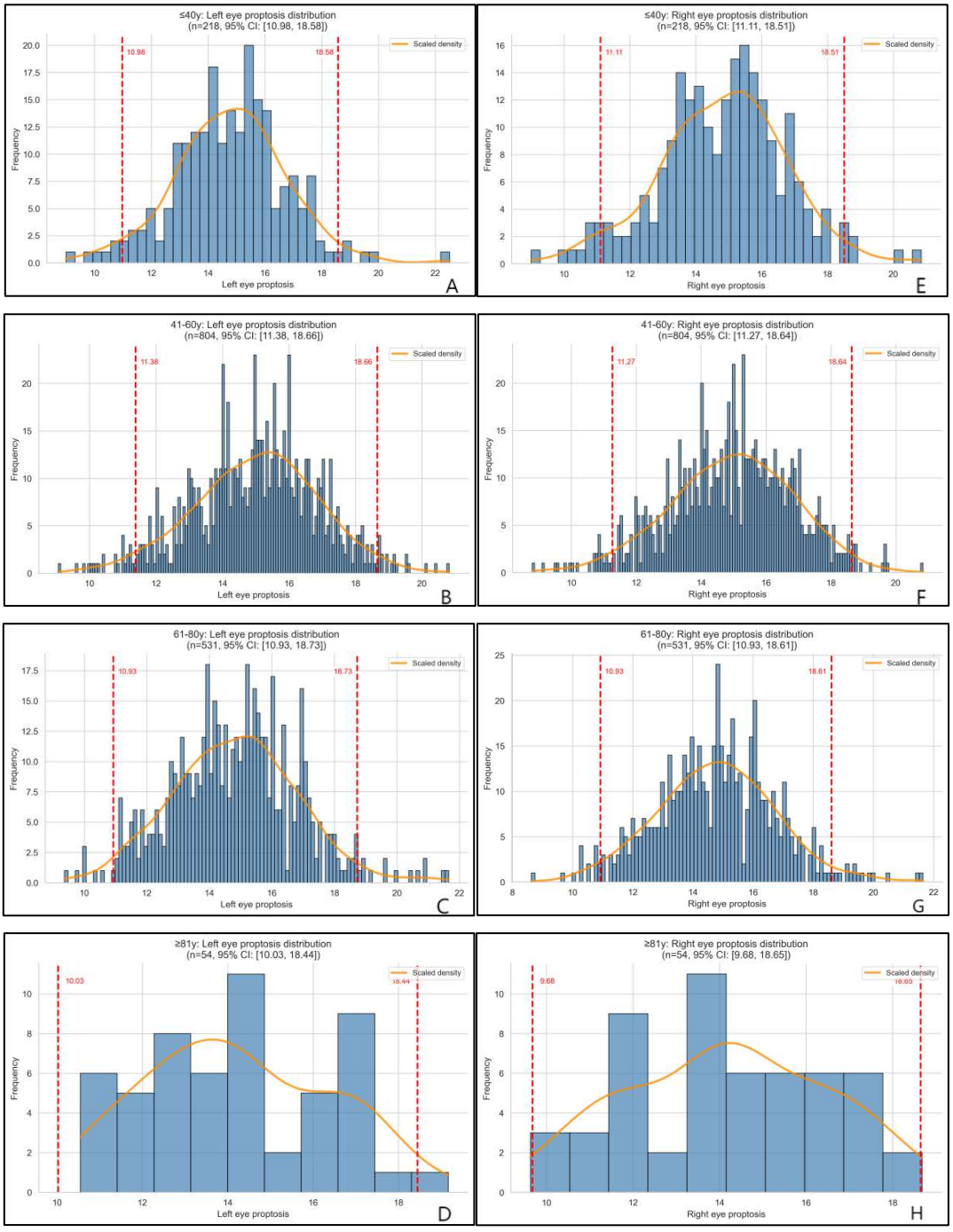
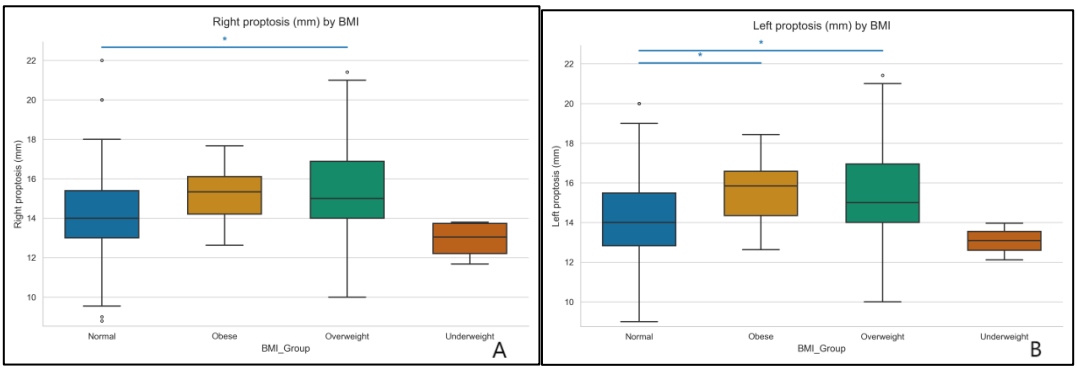
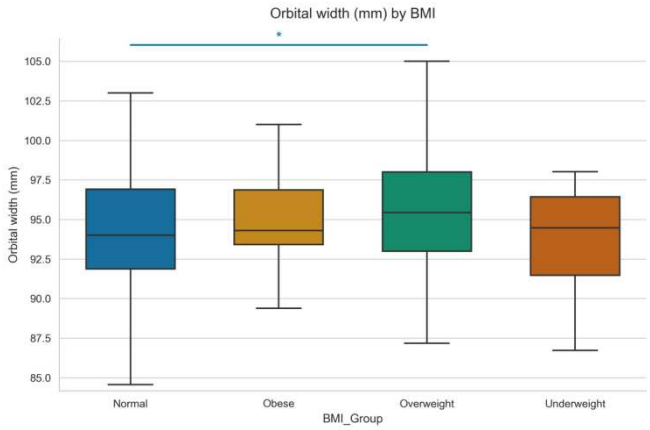


Figure 5 (A-D) Distribution, Central Tendency, and 95% Reference Ranges of Left Exophthalmos in Adult Women Across Four Age Groups; (E-H) Distribution, Central Tendency, and 95% Reference Ranges of Right Exophthalmos in Adult Women Across Four Age Groups.



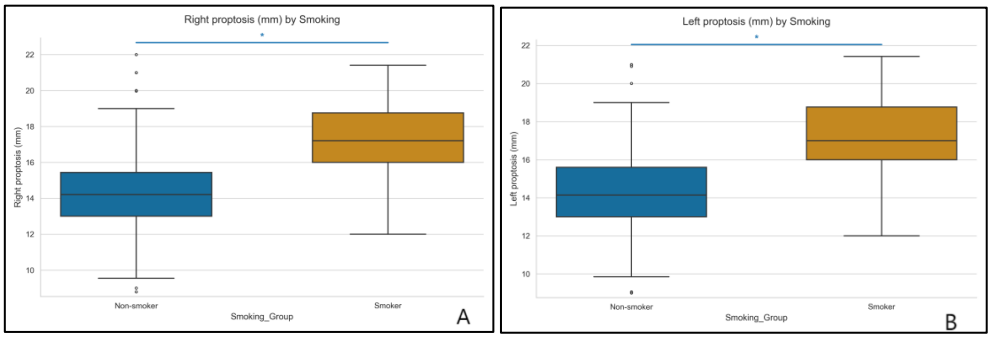
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428 Figure 6 (A) Right Exophthalmos by BMI Group; (B) Left Exophthalmos by BMI Group (mm).



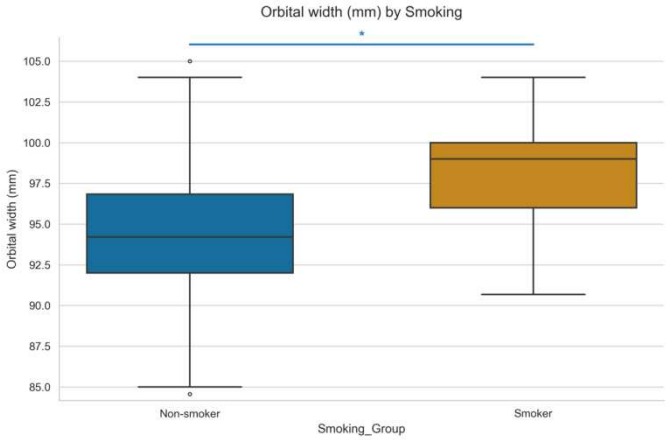
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430 Figure 7 Interorbital Distance by BMI Group (mm).



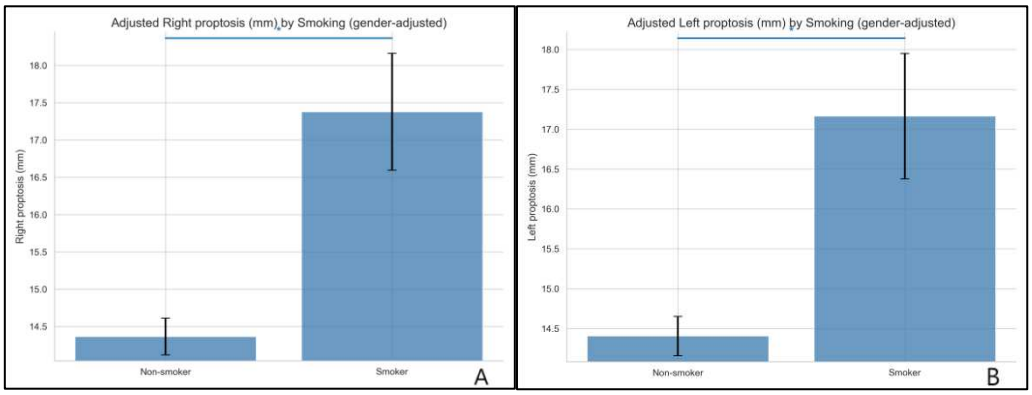
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432 Figure 8 (A) Right Exophthalmos by Smoking Status; (B) Left Exophthalmos by Smoking Status (mm).



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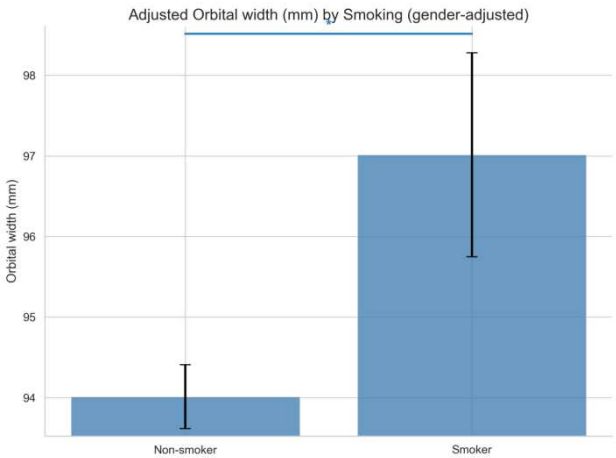
434 Figure 9 Interorbital Distance by Smoking Status (mm).



435

436 Figure 10 (A) Adjusted Right Exophthalmos by Smoking Status; (B) Adjusted Left Exophthalmos by Smoking Status (mm)

437 (Gender-Adjusted).



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439 Figure 11 Adjusted Interorbital Distance by Smoking Status (mm) (Gender-Adjusted).

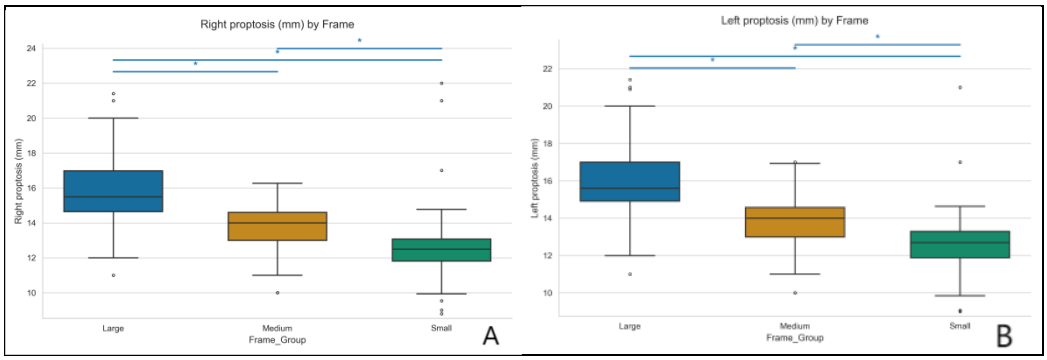


Figure 12 (A) Right Exophthalmos by Body Frame Size Group; (B) Left Exophthalmos by Body Frame Size Group (mm).

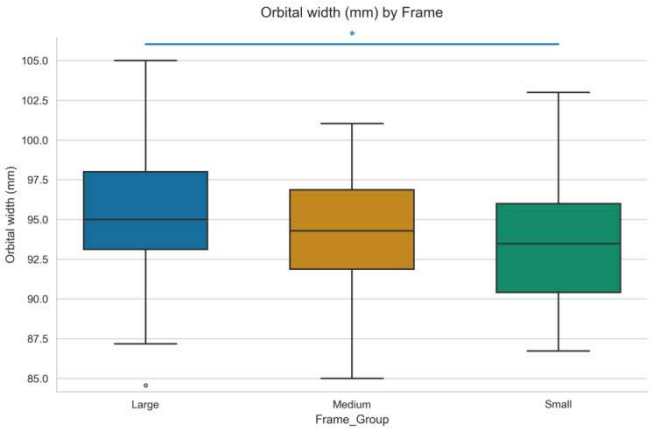


Figure 13 Interorbital Distance by Body Frame Size Group (mm).

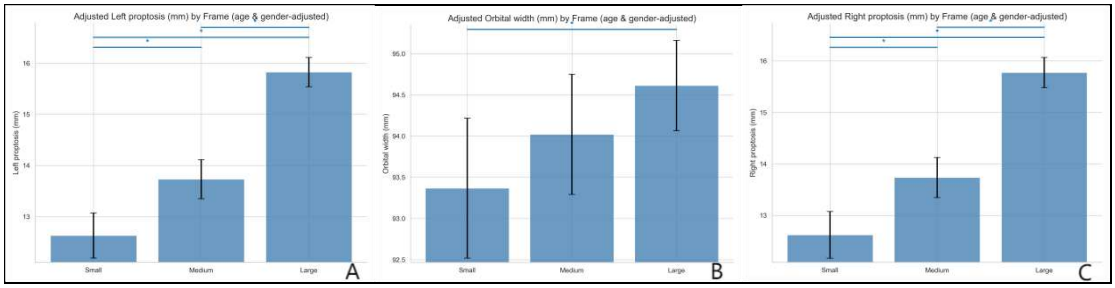


Figure 14 A: Adjusted Right Exophthalmos by Body Frame Size Group ;B: Adjusted Left Exophthalmos by Body Frame Size Group ;C: Adjusted Interorbital Distance by Body Frame Size Group (mm) (Age- and Gender-Adjusted).

448 **Table 1: Comparison of CT-measured exophthalmometry data and anatomical characteristics among**
449 **different populations in previous studies**

Population Group	Specific Subgroup/Region	Exophthalmometry (mm)	Distribution Characteristics	Anatomical Characteristics
African Descent	African American Adults	17.5-18.2	Highest protrusion among all ethnicities; significantly higher in males than females.	Associated with wider orbital cavity, shallower orbital floor, and facial soft tissue distribution.
Caucasian	Non-Hispanic White Adults (USA)	16.5-17.8	Exophthalmometry at medium-high level; slightly higher in males than females.	Orbits are often angular, with a moderate orbital depth-to-width ratio.
	Children & Adolescents (Lithuania)	16.6-17.6		
Asian Descent	East Asian (Korean)	14.8-15.6	Significantly lower than Caucasians.	Higher prominence rate of orbital fat, more pronounced with age.
	South Asian (South India)	14.7 ± 1.70	Lower than Caucasians and African Americans.	Orbits tend to be rounder and relatively shallower.
	West Asian (Iranian Adults)	16.3	Higher than other Asian groups, lower than Caucasians.	Orbital index similar to Omani population; anatomical features intermediate between Asian and Caucasian.
	West Asian (Iranian Adolescents)	17.1		

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Table 2: Descriptive statistics of right-eye exophthalmometry, left-eye exophthalmometry, and interorbital distance for each group

	Age Group	N	Mean	Standard Deviation
Right-eye Exophthalmometry	≤40 years	218	14.81013761	1.887652208
Right-eye Exophthalmometry	41-60 years	804	14.95451493	1.881814097
Right-eye Exophthalmometry	61-80 years	531	14.76879473	1.96057646
Right-eye Exophthalmometry	≥81 years	54	14.16240741	2.287966004
Left-eye Exophthalmometry	≤40 years	218	14.7783945	1.937648746
Left-eye Exophthalmometry	41-60 years	804	15.0213806	1.856180269
Left-eye Exophthalmometry	61-80 years	531	14.83184557	1.989923859
Left-eye Exophthalmometry	≥81 years	54	14.23666667	2.146972419
Interorbital Distance	≤40 years	218	94.50426606	3.311672369
Interorbital Distance	41-60 years	804	94.20598259	3.261581744
Interorbital Distance	61-80 years	531	94.39450094	3.180813039
Interorbital Distance	≥81 years	54	95.22574074	3.498967827

Table 3: Paired comparisons of exophthalmometry and interorbital distance within each age group

Factor	Age Group1	Age Group2	Method	Test Statistic	P-value
Right-eye Exophthalmometry	41-60 years	61-80 years	Tukey HSD	-0.1857	0.3101
Right-eye Exophthalmometry	41-60 years	≤40 years	Tukey HSD	-0.1444	0.7592
Right-eye Exophthalmometry	41-60 years	≥81 years	Tukey HSD	-0.7921	0.0181
Right-eye Exophthalmometry	61-80 years	≤40 years	Tukey HSD	0.0413	0.9933
Right-eye Exophthalmometry	61-80 years	≥81 years	Tukey HSD	-0.6064	0.1217
Right-eye Exophthalmometry	≤40 years	≥81 years	Tukey HSD	-0.6477	0.1195
Left-eye Exophthalmometry	41-60 years	61-80 years	Tukey HSD	-0.1895	0.2917
Left-eye Exophthalmometry	41-60 years	≤40 years	Tukey HSD	-0.243	0.348
Left-eye Exophthalmometry	41-60 years	≥81 years	Tukey HSD	-0.7847	0.0196
Left-eye Exophthalmometry	61-80 years	≤40 years	Tukey HSD	-0.0535	0.9858
Left-eye Exophthalmometry	61-80 years	≥81 years	Tukey HSD	-0.5952	0.1328
Left-eye Exophthalmometry	≤40 years	≥81 years	Tukey HSD	-0.5417	0.2487
Interorbital Distance	41-60 years	61-80 years	Tukey HSD	0.1885	0.7276
Interorbital Distance	41-60 years	≤40 years	Tukey HSD	0.2983	0.6257
Interorbital Distance	41-60 years	≥81 years	Tukey HSD	1.0198	0.1151
Interorbital Distance	61-80 years	≤40 years	Tukey HSD	0.1098	0.9751
Interorbital Distance	61-80 years	≥81 years	Tukey HSD	0.8312	0.2782
Interorbital Distance	≤40 years	≥81 years	Tukey HSD	0.7215	0.4619

Table 4: Descriptive statistics of right-eye exophthalmometry, left-eye exophthalmometry, and interorbital distance for each group (BMI analysis)

Variable	Group	N	Mean	Standard Deviation	Median	Q1	Q3	Min	Max	P-value*
Right-eye Exophthalmometry	**Normal**	184	14.1776087	2.12735777	14	13	15.3975	8.79	22	0.00105653
Right-eye Exophthalmometry	**Obesity**	19	15.23631579	1.50940095	15.34	14.21	16.105	12.63	17.67	0.679001615
Right-eye Exophthalmometry	**Overweight**	108	15.29953704	2.170984696	15	14	16.8875	10	21.41	0.0192532
Right-eye Exophthalmometry	**Underweight**	4	12.8925	1.036769823	13.045	12.205	13.7325	11.68	13.8	0.311234622
Left-eye Exophthalmometry	**Normal**	184	14.15597826	2.064151771	14	12.83	15.4825	9	20	0.015423016
Left-eye Exophthalmometry	**Obesity**	19	15.52894737	1.580481272	15.84	14.35	16.58	12.63	18.43	0.931608256
Left-eye Exophthalmometry	**Overweight**	108	15.32555556	2.179246776	15	14	16.9475	10	21.42	0.011420111
Left-eye Exophthalmometry	**Underweight**	4	13.0625	0.797093679	13.085	12.6	13.5475	12.12	13.96	0.949964961
Interorbital Distance	**Normal**	184	94.25679348	3.468709787	94	91.87	96.9175	84.56	103	0.46267237
Interorbital Distance	**Obesity**	19	95.04421053	3.274530188	94.3	93.405	96.86	89.38	101	0.714501405
Interorbital Distance	**Overweight**	108	95.50490741	3.554634594	95.435	93	98	87.17	105	0.340080784
Interorbital Distance	**Underweight**	4	93.4225	4.910440408	94.475	91.4675	96.43	86.72	98.02	0.646163149

Note: P-value likely refers to normality test.

Table 5: Descriptive statistics for pairwise group comparisons (BMI analysis)

Variable	Group1	Group2	Method	P-value
Right-eye Exophthalmometry	Normal	Obesity	Mann-Whitney U (Bonferroni)	0.010525971
Right-eye Exophthalmometry	Normal	Overweight	Mann-Whitney U (Bonferroni)	1.59782E-05
Right-eye Exophthalmometry	Normal	Underweight	Mann-Whitney U (Bonferroni)	0.132012576
Right-eye Exophthalmometry	Obesity	Overweight	Mann-Whitney U (Bonferroni)	0.804742812
Right-eye Exophthalmometry	Obesity	Underweight	Mann-Whitney U (Bonferroni)	0.013319893
Right-eye Exophthalmometry	Overweight	Underweight	Mann-Whitney U (Bonferroni)	0.009306739
Left-eye Exophthalmometry	Normal	Obesity	Mann-Whitney U (Bonferroni)	0.002797043
Left-eye Exophthalmometry	Normal	Overweight	Mann-Whitney U (Bonferroni)	1.18537E-05
Left-eye Exophthalmometry	Normal	Underweight	Mann-Whitney U (Bonferroni)	0.202757748
Left-eye Exophthalmometry	Obesity	Overweight	Mann-Whitney U (Bonferroni)	0.502503103
Left-eye Exophthalmometry	Obesity	Underweight	Mann-Whitney U (Bonferroni)	0.008354389
Left-eye Exophthalmometry	Overweight	Underweight	Mann-Whitney U (Bonferroni)	0.011938102
Interorbital Distance	Normal	Obese	Tukey HSD	0.7874
Interorbital Distance	Normal	Overweight	Tukey HSD	0.0185
Interorbital Distance	Normal	Underweight	Tukey HSD	0.9654
Interorbital Distance	Obese	Overweight	Tukey HSD	0.9521
Interorbital Distance	Obese	Underweight	Tukey HSD	0.8347
Interorbital Distance	Overweight	Underweight	Tukey HSD	0.6481

Table 6: Statistical description of smoking and non-smoking groups

Variable	Group	N	Mean	Standard Deviation	Median	Q1	Q3	Min	Max	P-value*
Right-eye Exophthalmometry	Non-smoker	286	14.33129371	1.955685209	14.205	13.00	15.4400	8.79	22.00	0.000183748
Right-eye Exophthalmometry	Smoker	30	17.278	2.320002081	17.21	16.00	18.7500	12.00	21.41	0.100482099
Left-eye Exophthalmometry	Non-smoker	286	14.37223776	1.95754229	14.145	13.00	15.5975	9.00	21.00	0.00204253
Left-eye Exophthalmometry	Smoker	30	17.05666667	2.391610817	17.00	16.00	18.7675	12.00	21.42	0.166066088
Interorbital Distance	Non-smoker	286	94.346	3.368468429	94.205	92.00	96.8425	84.56	105.00	0.197079443
Interorbital Distance	Smoker	30	98.26866667	3.124399786	99.00	96.00	100.0000	90.67	104.00	0.425057061

Note: P-value likely refers to normality test. "N" for smoker group appears as 0 in some rows but is corrected to 30 based on context.

Table 7: Descriptive statistics of right-eye exophthalmometry, left-eye exophthalmometry, and interorbital distance for each group (Body Frame analysis)

Variable	Group	N	Mean	Standard Deviation	Median	Q1	Q3	Min	Max	P-value*
Right-eye Exophthalmometry	Large Frame	174	15.70758621	1.807601141	15.485	14.64	16.98	11.00	21.41	0.000131817
Right-eye Exophthalmometry	Medium Frame	81	13.72975309	1.311385694	14.00	13.00	14.60	10.00	16.27	0.062027096
Right-eye Exophthalmometry	Small Frame	61	12.65344262	2.133685298	12.49	11.81	13.07	8.79	22.00	2.56546E-08
Left-eye Exophthalmometry	Large Frame	174	15.73649425	1.836032984	15.59	14.915	17.00	11.00	21.42	0.000369331
Left-eye Exophthalmometry	Medium Frame	81	13.72049383	1.378657772	14.00	13.00	14.58	10.00	17.00	0.256994346
Left-eye Exophthalmometry	Small Frame	61	12.66639344	1.840156726	12.70	11.88	13.30	9.00	21.00	7.71804E-06
Interorbital Distance	Large Frame	174	95.283	3.434807256	95.00	93.11	98.00	84.56	105.00	0.386401845
Interorbital Distance	Medium Frame	81	94.283	3.346452784	94.28	91.87	96.87	85.00	101.03	0.201387541
Interorbital Distance	Small Frame	61	93.66196721	3.788025792	93.47	90.41	96.00	86.72	103.00	0.338594147

Note: P-value likely refers to normality test. Mean for Interorbital Distance in Large/Medium frame groups is implied from adjacent cell.

Table 8: Pairwise group comparisons (Body Frame analysis, unadjusted)

Variable	Group1	Group2	Method	P-value
Right-eye Exophthalmometry	Large Frame	Medium Frame	Mann-Whitney U (Bonferroni)	2.38121E-16
Right-eye Exophthalmometry	Large Frame	Small Frame	Mann-Whitney U (Bonferroni)	3.53904E-22
Right-eye Exophthalmometry	Medium Frame	Small Frame	Mann-Whitney U (Bonferroni)	9.14973E-08
Left-eye Exophthalmometry	Large Frame	Medium Frame	Mann-Whitney U (Bonferroni)	2.87785E-16
Left-eye Exophthalmometry	Large Frame	Small Frame	Mann-Whitney U (Bonferroni)	7.26966E-22
Left-eye Exophthalmometry	Medium Frame	Small Frame	Mann-Whitney U (Bonferroni)	2.05097E-06
Interorbital Distance	Large Frame	Medium Frame	Tukey HSD	0.0976
Interorbital Distance	Large Frame	Small Frame	Tukey HSD	0.0055
Interorbital Distance	Medium Frame	Small Frame	Tukey HSD	0.5163

Table 9: Pairwise group comparisons after adjustment (Body Frame analysis)

Variable	Group1	Group2	P-value
Right-eye Exophthalmometry	Small Frame	Medium Frame	0.000252641
Right-eye Exophthalmometry	Small Frame	Large Frame	5.11328E-26
Right-eye Exophthalmometry	Medium Frame	Large Frame	1.43633E-15
Left-eye Exophthalmometry	Small Frame	Medium Frame	0.000215775
Left-eye Exophthalmometry	Small Frame	Large Frame	1.56219E-27
Left-eye Exophthalmometry	Medium Frame	Large Frame	7.10744E-17
Interorbital Distance	Small Frame	Medium Frame	0.24746663
Interorbital Distance	Small Frame	Large Frame	0.015149462
Interorbital Distance	Medium Frame	Large Frame	0.19246316

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