Metrics of anterior sclera in normal Chinese adults: Anterior segment imaging using the swept-source optical coherence tomography Running

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Research Article

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Abstract

**Background:** To measure the corneoscleral limbus and anterior sclera parameters of normal Chinese adults by swept-source optical coherence tomography (OCT).

**Methods:** In this cross-sectional study, a total of 56 Chinese subjects with ametropia were evaluated in the Eye Hospital of Wenzhou Medical University from September 2020 to December 2020, including 26 (46.4%) men, with an average age of 24.7±1.8 years old, and a spherical equivalent of -2.05±0.46 D. The optical coherence tomograph SS-1000 (CASIA, Tomey, Tokyo, Japan) was used to measure the sagittal height, corneoscleral junction angle (CSJ), corneal angle, and scleral angle. One-way analysis of variance and least significant difference test were used to compare the differences in the four segment parameters.

**Results:** The mean sagittal heights of the right eyes at chord lengths of 10.0, 12.3, and 15.0 mm were 1756±72, 2658±110, and 3676±155 μm, respectively. The absolute values of the differences between horizontal and vertical meridians at chord lengths of 10.0, 12.3, and 15.0 mm were 54±40, 70±67, and 117±95 μm, respectively. The differences of CSJ and corneal angles at 12.3 mm chord and scleral angle at 15.0 mm chord in the four segments were statistically significant (F values were 32.01, 21.31, and 13.37, respectively, all P values < 0.001). The CSJ angles from low to high were 176.53±2.14° (nasal), 178.66±1.84° (inferior), 179.13±1.20° (temporal), and 179.31±1.68° (superior), and 87.5% of the nasal angles were less than 179°. The corneal angles at 12.3 mm chord from high to low were 40.31±2.80° (nasal), 39.46±2.41° (temporal), 37.20±2.26° (inferior), and 37.50±2.28° (superior). The scleral angles at 15.0 mm chord from high to low were 38.35±2.47° (temporal), 38.26±3.37° (superior), 35.37±3.10° (nasal), and 35.30±4.71° (inferior).

**Conclusion:** The morphology of corneoscleral limbus and anterior sclera is asymmetrical in normal Chinese adults. The nasal side of the corneoscleral limbus has the largest angle, and the superior and temporal sides of the scleral angle are larger. From the corneoscleral limbus to the anterior sclera, the superior side becomes steep and the other segments become flat.

**Background**

Scleral lens, as one of the most important non-surgical treatment methods for ocular surface diseases, such as keratoconus, irregular astigmatism, and severe dry eye, has been widely used in clinical practice in recent years [1–3]. Scleral lens lands on the sclera and does not touch the corneal surface in nerve ends, thus, it has satisfactory imaging quality[4, 5] and comfort [6–8] and the proportion of its application in people with simple ametropia is gradually increasing.

It is important to obtain the morphology of corneoscleral limbus and sclera for fitting scleral lens. Swept source optical coherence tomography (SS-OCT) [9]can clearly display scleral images, and the maximum transverse imaging range is approximately 16.0 mm[10]. It can reliably display, segment, and quantify the morphology of cornea and sclera, and the angle and thickness can be measured in detail [11]. SS-OCT
possesses the advantages of wide imaging range, high sensitivity, and fast imaging in the morphological measurement of cornea and sclera.

To date, researchers have reported that the scleral morphology was asymmetric, the nasal side was flat[12–15] and the scleral angle was small[2, 13, 16]. However, the majority of subjects in these studies were Caucasians[15, 17] or Caucasians and Asians that were analyzed together[13]. There were differences in visible iris diameter [18], corneal curvature [19], corneal eccentricity value [20], and other parameters between Asians and Caucasians. Therefore, the scleral morphology of Asians needs to be measured urgently. In addition, in previous studies, different height values of chord length were mainly measured[17, 19, 21], and few studies concentrated on the corneoscleral junction angle and scleral angle. The present study aimed to quantitatively measure the sagittal height, corneal angle, corneoscleral junction angle, and scleral angle of normal Chinese adults using SS-OCT, in order to obtain the morphology of corneoscleral limbus and anterior sclera, and to provide a reliable reference for the fitting and design of contact lenses.

Methods

This cross-sectional study was conducted in the Eye Hospital of Wenzhou Medical University (Wenzhou, China) from September 2020 to December 2020, and 56 subjects with simple refractive errors were enrolled.

Inclusion criteria were as follows: 1) age from 20 to 40 years old; 2) no contact lens wearing history, or stopping wearing rigid gas permeable contact lens or orthokeratology lens for at least 4 weeks, or stopping wearing soft contact lens for at least 2 weeks; 3) no other systemic or ocular diseases, such as hypertension, diabetes, keratoconus, corneal ectasia, etc.; 4) the best corrected visual acuity (BCVA) ≥ 20/20; 5) no history of ocular trauma and surgery (e.g., refractive surgery history, etc.).

Exclusion criteria were as follows: 1) corneal diseases, such as keratitis, corneal clouding, corneal leukemia, etc.; 2) conjunctival diseases (e.g., pterygium and conjunctivitis); 3) poor fixation and inability to cooperate with instrumental measurement.

The present study followed the Declaration of Helsinki, and it was approved by the Ethics Committee of the Eye Hospital of Wenzhou Medical University (Approval No. 2020-J-41). All participants signed the informed consent form.

The sagittal heights of the nasal-temporal and superior-inferior (corresponding to the horizontal and vertical meridians, respectively) at chord lengths of 10.0, 12.3, and 15.0 mm, the corneoscleral junction (CSJ) angles of four segments (nasal, temporal, superior, and inferior, corresponding to 0°, 90°, 180°, and 270°), the corneal angle at chord length of 12.3 mm, and the scleral angle at chord length of 15.0 mm were measured by the same examiner (SYQ) using the optical coherence tomograph SS-1000 (CASIA, Tomey, Tokyo, Japan), which referred to Ritzmann et al.'s measurement method[15]. The anterior chamber angle scan mode was used, and the chord length of 12.3 mm was selected as the location of
the corneoscleral limbus. The data were analyzed by ImageJ 1.48h3 software (National Institutes of Health, Bethesda, CA, USA). The corneoscleral transition zone was also classified based on the CSJ angles according to Hall et al.’s classification criteria[13] as concave (CSJ angle < 179°), flat (179° ≤ CSJ angle ≤ 181°), and convex (CSJ angle > 181°).

Both eyes were measured, and each eye was measured at least three times until the image quality was satisfactory. The criteria for satisfactory image quality were the absence of artifacts in both horizontal and vertical meridians obtained with the same scan and the measurement range was more than 15.0 mm. After each measurement, it was necessary to refocus to avoid interdependence of consecutive measurements. The measurements were carried out between 10:00 and 16:00, three hours after the subjects woke up to mitigate the effects of sleep on corneal morphology[22].

SPSS 25.0 software (IBM, Armonk, NY, USA) was used to perform statistical analysis. All data met normal distribution by Shapiro-Wilk test (all P > 0.05) and were expressed as mean ± standard deviation. Differences in sagittal height on the horizontal and vertical meridians were compared by independent-samples t-test, and differences in corneal angle, CSJ angle, and scleral angle in the four segments were compared by one-way analysis of variance (ANOVA) and least-significant difference test. Only data from the right eye were analyzed, and P < 0.05 was considered statistically significant.

**Results**

A total of 56 subjects were enrolled in this study, including 26 (46.4%) men and 30 (53.6%) women. Their mean age was 24.7 ± 1.8 years old, all subjects were Chinese, with a right eye stereoscopic equivalent of -2.05 ± 0.46 D.

**Sagittal heights at chord lengths of 10.0, 12.3, and 15.0 mm**

The sagittal heights at 10.0 mm chord were 1734 ± 71 and 1779 ± 67 µm for the horizontal and vertical meridians, respectively, 2664 ± 122 and 2653 ± 96 µm at 12.3 mm chord, and 3680 ± 168 and 3672 ± 141 µm at 15.0 mm chord, respectively. The differences between two meridians were not statistically significant (P = 0.222, 0.382, and 0.632 respectively, Table 1).
### Table 1
Comparison of sagittal heights at different segments and chord lengths (n = 56)

<table>
<thead>
<tr>
<th>Chord length (mm)</th>
<th>Nasal-temporal (µm)</th>
<th>Superior-inferior (µm)</th>
<th>Mean value (µm)</th>
<th>Difference value (µm)</th>
<th>t value</th>
<th>P value</th>
<th>Absolute value of difference (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>1734 ± 71</td>
<td>1779 ± 67</td>
<td>1756 ± 72</td>
<td>-45 ± 56</td>
<td>1.05</td>
<td>0.222</td>
<td>54 ± 40</td>
</tr>
<tr>
<td>12.3</td>
<td>2664 ± 122</td>
<td>2653 ± 96</td>
<td>2658 ± 110</td>
<td>-11 ± 100</td>
<td>0.88</td>
<td>0.382</td>
<td>70 ± 67</td>
</tr>
<tr>
<td>15.0</td>
<td>3680 ± 168</td>
<td>3672 ± 141</td>
<td>3676 ± 155</td>
<td>8 ± 100</td>
<td>0.42</td>
<td>0.632</td>
<td>117 ± 95</td>
</tr>
</tbody>
</table>

*Independent-samples t-test*

The absolute values of the difference between horizontal and vertical meridians were 54 ± 40, 70 ± 67, and 117 ± 95 µm at 10.0, 12.3, and 15.0 mm chord, respectively. Besides, 57.1% (32) of subjects had an absolute value of less than 50 µm at 10.0 mm chord, and 50.0% at 12.3 mm chord. This percentage decreased to 19.6% at 15.0 mm chord, as shown in Fig. 1.

### CSJ angle

The CSJ angles from low to high were 176.53 ± 2.14° (nasal), 178.66 ± 1.84° (inferior), 179.13 ± 1.20° (temporal), and 179.31 ± 1.68° (superior), with statistically significant differences (F = 32.01, P < 0.001, Table 2).
Table 2
Comparison of measurements in different segments (n = 56)

<table>
<thead>
<tr>
<th>Segment</th>
<th>Corneoscleral junction angle (°)</th>
<th>Corneal angle at 12.3 mm chord (°)</th>
<th>Scleral angle at 15.0 mm chord (°)</th>
<th>Difference of two angles (°)</th>
<th>t value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasal</td>
<td>176.53 ± 2.14</td>
<td>40.31 ± 2.80</td>
<td>35.37 ± 3.10</td>
<td>4.94 ± 3.34</td>
<td>-0.48</td>
<td>0.020</td>
</tr>
<tr>
<td>Temporal</td>
<td>179.13 ± 1.20</td>
<td>39.46 ± 2.41</td>
<td>38.35 ± 2.47</td>
<td>1.10 ± 3.43</td>
<td>1.45</td>
<td>0.030</td>
</tr>
<tr>
<td>Superior</td>
<td>179.31 ± 1.68</td>
<td>37.20 ± 2.26</td>
<td>38.26 ± 3.37</td>
<td>-1.06 ± 3.42</td>
<td>-3.47</td>
<td>0.020</td>
</tr>
<tr>
<td>Inferior</td>
<td>178.66 ± 1.84</td>
<td>37.50 ± 2.28</td>
<td>35.30 ± 4.71</td>
<td>2.20 ± 4.59</td>
<td>-1.32</td>
<td>0.020</td>
</tr>
<tr>
<td>F value</td>
<td>32.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>a</sup> One-way analysis of variance test; <sup>b</sup> Independent-samples t-test

The differences were –2.60 ± 0.32°, -2.78 ± 0.32°, and −2.13 ± 0.32° on the nasal side compared with the temporal, superior, and inferior sides, respectively, with statistically significant differences (all P < 0.001). There were no statistically significant differences in the temporal, inferior, and superior sides of pairwise comparisons among the three groups (all P > 0.05) (Table 3).
The peak value of nasal CSJ angle was <179°, and the peak values of the temporal, inferior, and superior CSJ angles all occurred at the range of 179–181° (Fig. 2).

Moreover, 87.5% of CSJ angles on the nasal side were <179°, and the temporal, inferior, and superior CSJ angles were predominantly 179–181° (57.1%, 55.4%, and 57.1%, respectively).

### Corneal and scleral angles

The corneal angles of 12.3 mm chord from high to low were 40.31 ± 2.80° (nasal), 39.46 ± 2.41° (temporal), 37.20 ± 2.26° (inferior), and 37.50 ± 2.28° (superior), with statistically significant differences (F = 21.31, P < 0.001, Table 2). The differences were 0.85 ± 0.46°, 3.11 ± 0.46°, and 2.81 ± 0.46° on the nasal side compared with the temporal, superior, and inferior sides, respectively, with statistically significant differences (P = 0.007, < 0.001, and < 0.001, respectively). The differences were 2.26 ± 0.46° and 1.96 ± 0.32° on the temporal side compared with the superior and inferior sides, respectively, which were statistically significant (both P < 0.001). No statistically significant difference was found between the superior and inferior sides (P = 0.532) (Table 3).

The scleral angles of 15.0 mm chord from high to low were 38.35 ± 2.47° (temporal), 38.26 ± 3.37° (superior), 35.37 ± 3.10° (nasal), and 35.30 ± 4.71° (inferior), with statistically significant differences (F = 13.37, P < 0.001, Table 2). The differences were 2.89 ± 0.66° and 2.95 ± 0.66° on the superior side compared with the nasal and inferior sides, respectively, which were statistically significant (both P <
The differences were 2.98 ± 0.66° and 3.05 ± 0.66° on the temporal side compared with the nasal and inferior sides, respectively, which were statistically significant (both P < 0.001). No statistically significant differences were found between the superior and temporal sides and the nasal and inferior sides (P = 0.892 and 0.922, respectively), as shown in Table 3.

**Comparison between corneal angle and scleral angle**

With comparing the changes between the corneal angle at 12.3 mm chord and the scleral angle at 15.0 mm chord, the overall morphology of the ocular surface varying from the corneal limbus to the anterior sclera could be obtained. The corneal angle was lower than the scleral angle on the superior side (difference value was −1.06 ± 3.42°), with a statistically significant difference (P = 0.020), and the corneal angles were higher on the nasal, inferior, and temporal sides (the difference values were 4.94 ± 3.34°, 2.20 ± 4.59°, and 1.10 ± 3.43°, respectively), with statistically significant differences (P = 0.020, 0.002, and 0.020, respectively), with the largest difference on the nasal side (Table 2, Fig. 3).

**Discussion**

The present study provided new insights into the shape of the anterior sclera by measuring the sagittal height and ocular angles among four radial segments in Chinese adults. The results showed that the overall anterior scleral morphology was asymmetry, which is similar to findings of previous studies on Caucasians[13, 15, 16], while there were some detailed differences, such as lower sagittal height at the corneoscleral limbus and sclera, the scleral limbus transition area was smoother, and the nasal sclera was flatter.

**Sagittal heights at chord lengths of 10.0, 12.3, and 15.0 mm**

The sagittal heights of the ocular surface at different chord lengths are crucial for fitting of various contact lenses (e.g., keratoplasty, scleral lenses, etc.). In the present study, the mean sagittal heights at 10, 12.3, and 15.0 mm chord lengths were 1756, 2658, and 3676 µm, respectively. Hall et al. [13] found that the sagittal height at 10 mm chord length was 1750 µm, which was close to the results of the present study, while the research population covered 67% of Caucasians, 28% of Asians, and 5% of other races. As the corneoscleral limbus is a region with a width of approximately 1 mm[13], studies on Caucasians mainly used a fixed chord length (12.8 mm[13, 15] or 13.0 mm[17]) as the location of corneoscleral limbus. Nevertheless, the mean horizontal visible iris diameter in Chinese was 11.3 mm[19, 20], thus, 12.3 mm was selected as the location of the corneoscleral limbus in the present study. Some studies reported that the mean sagittal height of the corneoscleral limbus in Caucasians ranged from 2810 to 2940 µm[15, 17], both were higher than those achieved in the present study, which could be related to the fact that the chord lengths (12.8 mm[15] or 13.0 mm[17]) used in these studies were greater than 12.3 mm. However, even when the same chord length of 15.0 mm was used, the sagittal height in Caucasians ranged from 3740 to 3780 µm [15–17, 21], both were higher than 3676 µm achieved in the present study.
We infer that the sagittal height of the corneoscleral limbus sclera in Chinese was lower than that in Caucasians, and it could be attributed to the flatter corneal morphology and smaller visible iris diameter in Chinese population. However, the above-mentioned four studies all had a small sample size, and the differences in sagittal height among different ethnic groups need to be further verified in studies with the larger sample size.

**CSJ, corneal, and scleral angles**

The present study also showed morphological asymmetry at the corneoscleral limbus, with the smallest nasal CSJ angle, a concave transition compared with the other temporal, superior, and inferior sides, which was similar to previous studies on Caucasians. Furthermore, 45.1% of CSJ angles in the present study were within $180 \pm 1^\circ$ compared with 22.0% in Caucasians, suggesting that the morphology of the scleral limbus transition zone was relatively smooth in Chinese population compared with that in Caucasians. The present study also revealed an asymmetry in scleral morphology, with the scleral angle that was flatter on the nasal and inferior sides and steepest on the superior and temporal sides, which were also similar to previous studies on Caucasians. The mean nasal scleral angle in the present study was 35.37°, which was lower than the results of Ritzmann et al. (36.36°) and Sorbara et al. (39.32°). The scleral angle is closely associated with the local compression of the bulbar conjunctival vessels after lens wearing, and if the scleral angle at 15.0 mm chord is less than 36°, ophthalmologists need to be alert to lens compression of the conjunctival vessels. This also suggests that scleral lenses for the Chinese population need to be relatively flat on the nasal side of the scleral landing zone to obtain a good fit.

**Scleral symmetry**

Symmetry of corneal morphology is an important factor for lens centration, as well as being a crucial basis for selecting spherical and aspherical lenses. Whether the sclera is spherical can be determined by differences in various parameters on the horizontal and vertical meridians, such as visible iris diameter, angular scleral limbus width, and sagittal height difference of 15.0 mm chord. As the diameter of cornea increases, the scleral asymmetry also increases gradually. The percentage of horizontal and vertical meridians with sagittal height difference less than 50 µm at 10 mm chord in the present study was 57.1%, 50.0% at 12.3 mm chord, and this percentage decreased to 19.6% at 15.0 mm chord. For non-spherical sclera, the lens may require complex geometry, such as curved surfaces or irregular designs in specific areas to achieve central positioning. Therefore, the smaller the lens diameter, the higher the percentage of lenses with spherical design, and the larger the lens diameter, the higher the percentage of lenses with aspherical design. In addition, the symmetry of the scleral angle was found to be closely correlated with the final selection of spherical lenses during clinical fitting, thus, whether the scleral angle can be used for spherical assessment of the sclera will be further verified by subsequent studies.
**Potential factors influencing scleral shape**

The mechanism of the asymmetry in the morphology of the corneoscleral limbus to the anterior sclera remains unclear. It may be related to the anatomical position of the rectus oculi. The four rectus oculi are asymmetrically positioned at their stops on the anterior scleral surface, with the nasal medial rectus being closest to the stop from the corneoscleral limbus\[12, 14\] and more likely to pull on the nasal cornea. It may also be related to factors, such as eyelid position and strength [24, 25], eye axis length [26], and age[27].

**Study limitations**

The present study has some limitations. This study is not a large sample-sized study, and subjects were selected from a non-random sample, making the extrapolation of the study findings somewhat limited. This study only analyzed the sagittal height difference on the horizontal and vertical meridians, and the sagittal height difference on the two main meridians could be larger.

**Conclusions**

The present study showed the shape of the anterior sclera by measuring the sagittal height and ocular angles among four radial segments in Chinese adults, which is similar to previous studies on Caucasians. The anterior scleral morphology in this sample population was asymmetry, with the largest nasal angle at the corneoscleral limbus and a predominantly concave transition, and the other three segments tended to a tangential transition. The superior and temporal scleral angles were larger, and the nasal and inferior sides were flatter. From the corneoscleral limbus to the anterior sclera, the superior part become steeper and the remaining segments become flatter.

However, there were some detailed differences, such as a lower sagittal height at the corneoscleral limbus and sclera, and the scleral limbus transition area was smoother and the nasal sclera was flatter, providing a reliable reference for fitting and design of clinical contact lenses in the Chinese population.

**Abbreviations**

Optical coherence tomography (OCT), Corneoscleral junction angle (CSJ), Swept source optical coherence tomography (SS-OCT), The best corrected visual acuity (BCVA)

**Declarations**

**Ethics approval and consent to participate:** The present study followed the Declaration of Helsinki, and it was approved by the Ethics Committee of the Eye Hospital of Wenzhou Medical University (Approval No. 2020-J-41). The informed consent obtained was written and all participants signed the informed consent form.
Consent for publication: Not applicable

Availability of data and materials: The datasets analysed during the current study available from the corresponding author on reasonable request.

Competing interests: The authors declare that there is no conflict of interest.

Authors' contribution statement: N L: data analysis and interpretation, writing the manuscript, revising manuscript, and obtaining research funding; YqS: project design, data collection, data analysis and interpretation, and writing the manuscript; MyY: data analysis and writing the manuscript; BcC: data analysis and writing the manuscript; JI M: data collection; Ys L: data analysis and graphing; RzD: project design, critical review of the intellectual content of the manuscript, and obtaining research funding. All authors read and approved the final manuscript.

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References


**Figures**

![Graph showing distribution of absolute values of the difference between horizontal and vertical meridians in sagittal height at different chord lengths (n=56)](image_url)

**Figure 1**

Distribution of absolute values of the difference between horizontal and vertical meridians in sagittal height at different chord lengths (n=56)
Figure 2

Relative frequency distribution of the corneoscleral junction angle measurements at chord length of 12.3 mm (n=56, the shaded area represents the segment, indicating the most deviation of measurements from the average of all segments)
Figure 3

Average angles on the four principal meridians (n=56, the inner ring describes the angle that forms at the 12.3 mm chord and the outer ring describes the angle that forms at the 15.00 mm chord)