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An analysis of anterior scleral shape and its role in the design and fitting of scleral contact lenses

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ABSTRACT

Purpose: The purpose of this study was to evaluate the shape of the anterior sclera by measuring the sagittal height and corneoscleral transition angles in the four cardinal and four oblique segments of the eye.

Materials and methods: In this study, 78 normal eyes of 39 subjects were evaluated. The sagittal height, corneoscleral angle and scleral angle were measured at three chord lengths (10.0 mm, 12.8 mm and 15.0 mm) in all eight segments of the anterior eye using optical coherence tomography (Zeiss Visante AS-OCT). Scleral toricity was calculated for each eye, defined as the greatest sagittal height difference found between two perpendicular meridians.

Results: At a 12.8 mm chord length, the shape of the anterior eye was found to be nearly rotationally symmetric, and at a chord of 15.0 mm the shape became more asymmetric. The average sagittal heights of the eight segments at a 12.8 mm chord ranged from 2890 μm to 2940 μm; at a 15.0 mm chord they ranged from 3680 μm to 3790 μm. The average scleral angles at a 15.0 mm chord ranged from 35.17° to 38.82°. Significant differences between opposing segments were found in the sagittal height and scleral angle measurements at a chord of 15.0 mm (sagittal height $p \leq 0.0021$; scleral angle $p \leq 0.0105$). The nasal measurements revealed flatter scleral angles and concave corneoscleral transitions, whereas temporal scleral angles were steeper, with tangential or convex corneoscleral transitions.

Conclusion: These findings are important to consider when designing and fitting contact lenses that rest beyond the boundaries of the limbus, such as scleral lenses.

1. Introduction

The advent of videokeratoscopy in the early 1990's provided practitioners with new insights into the shape of the corneal surface across chords of 8.0–10.0 mm. More recently, through the use of composite corneal topography, it is possible to map the shape of the entire corneal surface from limbus to limbus. With the growing interest in contact lens designs that extend beyond the limbus, including modern scleral and soft contact lenses, researchers and clinicians have the need to look beyond the boundaries of the cornea to gain a greater understanding of anterior ocular shape and its impact on lens design [1–13].

The modern renaissance of scleral lenses has been made possible through the simultaneous development and merging of a number of technologies [14–18]. The availability of large diameter buttons of highly oxygen permeable materials, advances in computer controlled lathing techniques, and sophisticated lens design and fitting methods have all contributed to the success of this lens modality. Today scleral lenses serve as a primary tool in managing a wide range of conditions, including irregular astigmatism, ocular surface disease, and even normal refractive error [11,19–26].

Several studies have reported on the use of anterior segment OCT to describe the shape of the sclera by sagittal height [3,5–8], scleral radii [5–8,13,27] and scleral tangent angles [6,7,28]. A common finding was that the nasal sclera was flatter than the temporal in radii [6,7,13,27] and in terms of angle was smaller (lower angle) [5–7]. Additionally, authors have found consistent values of mean scleral sagittal depth at a chord of 15.0 mm, yet a strong disagreement exists among studies on scleral radii (Table 1). Additional biometric data of the anterior eye relevant to the design and fitting of contact lenses that rest beyond the limbus are displayed in Table 2.

Today, a number of questions related to scleral shape remain unanswered. For example, is the scleral surface spherical, toric, or

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Table 1
Previous investigations of the anterior scleral shape by sagittal height (µm) and scleral radius (mm) imaged with the Visante OCT.

Ref.	n	n eyes	Age	Gender	Pathology	Sag 15 mm Horizontal (µm)	Sag 15 mm Vertical (µm)	Sag 15 mm MEAN (µm)	Radius Nasal (mm)	Radius Temporal (mm)
[5]	40	40	32	68% F	N/A	3740	N/A	3740	N/A	N/A
[6]	50	100	22.8 ± 5.0	70% F	normal	3740	3770	3760	45.0	25.3
[7]	204	204	34.9 ± 15.2	65% F	normal	3700	3750	3730	35.5	22.4
[8]	14	14	33 ± 7	79% F	normal	3710[a]	3700[b]	3710	N/A	N/A
	14	14	40 ± 14	36% F	keratoconus	3410[a]	3930[b]	3670	N/A	N/A
[13]	24	N/A	31.3 ± 6.5	50% F	normal	N/A	N/A	N/A	13.33[c]	12.32[c]
[27]	24	24	N/A	N/A	normal	N/A	N/A	N/A	13.68	11.73

[a] flat meridian.
[b] steep meridian.
[c] best-fit circle.

Table 2
Previous investigations of horizontal visible iris diameter (HVID), vertical visible iris diameter (VVID), and palpebral aperture.

Author	Ethnicity	n	n Eyes	Age	Gender	HVID (mm)	VVID (mm)	Palpebral Aperture (mm)
[29]	–	–	–	–	–	12.00	11.00	–
[30]	–	–	–	–	–	11.70	10.60	–
[31]	Caucasian	390	743	10–80	40% F	11.71	–	–
[6]	British Asian/Caucasian	50	100	23 ± 5	70% F	11.86	–	10.89
[32]	Nigerians	130	–	48 ± 17	41% F	11.39	10.51	–
[7]	British Asian/Caucasian	204	204	35 ± 15	65% F	11.70	–	10.20
[8]	–	14	14	33 ± 7	79% F	11.77	–	–

asymmetric? The present study was designed to gain a greater understanding of the shape of the anterior sclera. This knowledge will serve an important role in the development of future contact lens designs that rest beyond the limbus.

2. Materials and methods

This study was conducted in accordance with the tenets of the Declaration of Helsinki. In this cross-sectional study, the scleral contour of 78 normal eyes from 39 subjects was measured in eight primary meridians. Excluded from the study were subjects with inflammatory or ectatic conditions that may affect the elevation of the cornea, conjunctiva (pingueculae), episclera, and sclera. Also excluded were subjects with any history of ocular surgery. Daily soft contact lens wearers were requested to discontinue lens wear at least three days prior to data collection, and rigid gas permeable (RGP) and extended wearers (EW) at least ten days prior.

The Visante OCT (Carl Zeiss Meditec, Dublin, CA, USA) was used to measure the sagittal height of the anterior sclera at three different chord lengths of 10.0, 12.8, and 15.0 mm in all eight primary meridians at 0, 45, 90, 135, 180, 225, 270 and 315°. The 10.0 mm chord length was chosen as the largest chord for which the data could be compared to corneal topography measurements. The 12.8 mm chord was chosen to represent the beginning of the scleral tissue, 1.0 mm larger than the average HVID, and the 15.0 mm chord was chosen as the largest chord length that could be consistently measured with the OCT images. To provide additional information regarding the shape of the sclera, the corneoscleral angles were also measured at chords of 12.8 and 15.0 mm in all eight meridians.

The "Anterior Segment Quad" scan was used to image the four quadrants in cross-sections at 180, 45, 90 and 135°. This scan images the four quadrants simultaneously, allowing for accurate measurement and comparison between the eight segments (Fig. 1). To capture a full view of the anterior segment, the superior and inferior eyelids of the subjects were manually held open without applying any pressure to the globe.

Corneal topography was performed using the Medmont E300 corneal topographer (Medmont International Pty Ltd, Victoria, AUS), and each subject's objective refraction was assessed using the Grand Seiko WAM-5500 (Shigya Machinery Works Ltd, Fukuyama City, Hiroshima, Japan). The Haag Streit BQ900 photo slit lamp (Haag-Streit AG, Koeniz, Switzerland) and the MB-Ruler software (MB-Software solutions, Iffezheim, Germany) were used to analyze the palpebral aperture and horizontal and vertical visible iris diameters (Fig. 2).

The sagittal height and scleral angles were measured with the built-in caliper tool of the Visante Analysis Software. To set a reference line for the measurement calipers, landmarks on the anterior ocular surface were used, as opposed to internal landmarks such as the iris root or scleral spur. In each cross-sectional image, the external junction of the cornea and sclera was used to define the boundaries of the corneal diameter (Fig. 3). To locate the termination of the cornea on the anterior surface, the scleral spur was first identified, and a caliper was drawn from the scleral spur to the anterior surface, perpendicular to a line tangent to the surface. The corneal diameter was defined as the distance between the two opposing endpoints in each cross section. This method is similar to that used by ocular pathologists [30,33]. The distance between the opposing scleral spur locations was defined as the scleral spur to scleral spur distance. The anterior chamber tool placed at the two endpoints that mark the external corneal diameter was considered as the line of reference for all measurements at the three chord lengths of 10.0 mm 12.8 mm and 15.0 mm (Fig. 4). Sagittal height was measured as the distance (µm) from the ocular surface at each chord length to a line tangent to the corneal apex and parallel to the reference line described above. Therefore, the lower the sagittal height number, the greater the elevation of the tissue, and the higher the sagittal height number, the lesser the elevation. The corneal angle was measured using the anterior chamber angle-tool, and was formed by the 12.8 mm chord (parallel to the reference line) and a line along the corneal surface that connects the 10.0 mm and 12.8 mm chord endpoints. The scleral angle was similarly measured by placing the angle-tool at the junction of the 15.0 mm chord endpoint and a line connecting the 12.8 mm and 15.0 mm chords. The corneo scleral junction (CSJ) angle was measured as the external angle formed between the line connecting the 10.0 mm and 12.8 mm chords and the line connecting the 12.8 mm and 15.0 mm chords. The CSJ angle describes the transition from cornea to sclera as either concave (<180°), tangential (=180°) or convex (>180°). The