



Relationship of placido corneal topography data with scleral lens fitting parameters



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ABSTRACT

Purpose: To analyze the relationship between corneal sagittal height and asymmetry parameters derived from Placido-videokeratoscopy with the parameters of fitted scleral lenses (ScCLs).

Methods: Corneal topographies were measured with MedmontE300 in a total of 126 eyes with irregular and regular corneas before ScCL fitting were analyzed. Measurements of sagittal height (OC-SAG) at steep and flat corneal meridians were obtained for 10 mm and 12 mm chords. Estimated Height (EHChord) parameters were taken for a chord equal to the diameter of the lens that each subject was wearing at different semi-meridians. Corneal asymmetry (difference in OC-SAG between steep and flat corneal meridians) was also assessed. These outcomes were correlated to ScCL parameters that subjects were wearing after 1 month.

Results: The mean ScCL-SAG was $4696 \pm 240 \mu\text{m}$, and the mean OC-SAG ranged from $1891 \mu\text{m}$ (10 mm), $2914 \mu\text{m}$ (12 mm), and between $4162 \mu\text{m}$ and $4251 \mu\text{m}$ for EH0-180° and EH30-210°. Stronger correlations ($p < 0.001$) between OC-SAG and ScCL-SAG were determined for EH0-180° ($r = 0.595$) and EH30-210° ($r = 0.618$). The mean differences between OC-SAG and ScCL-SAG were between $447 \pm 290 \mu\text{m}$ (EH0-180°) and $389 \pm 360 \mu\text{m}$ (EH30-210°). There was no relationship between corneal asymmetry and the need to fit a ScCL with toric haptic design in irregular corneas. Orientation of flat corneal and scleral meridians were similar only in corneas with high regular astigmatism.

Conclusions: EHChord attributes were the parameters that best correlated with the ScCL-SAG. The corneal asymmetry was shown to be a poor predictor for the need to fit a ScCL with toricity at landing zone in irregular corneas, but could have some predictive power in regular corneas.

1. Introduction

Scleral-supported contact lenses rest in the scleral region, vaulting the limbus and cornea. Their use has increased exponentially as several manufacturers have entered the global market providing refined fitting trials and methods as well as reproducible computer lathing techniques in high-oxygen-permeable materials [1,2]. With these fitting approaches, it is now possible to achieve successful fittings with minimal trial lenses and fewer lens exchanges after dispensing (Macedo-de-Araujo et al., 2017 submitted for publication).

The main challenges with fitting these lenses remain the estimation of the appropriate vault to avoid contact with the cornea while not being so excessive that it could interfere with the corneal physiology [3–5] and choosing the right ScCL landing zone geometry to match the scleral shape [6]. The shape of the anterior eye, namely the scleral

shape, has increasingly been studied over the last few years mainly because of the resurgence of ScCLs in the global market. Despite great advances in anterior segment (AS) imaging for ScCL fitting, such as anterior segment optical coherence tomography (AS-OCT) [7–9] and scleral topographers [10,11], their use to aid ScCL fitting remains restricted to few clinical practices around the world because of the current costs of this kind of technology. On the other hand, corneal topographers have become increasingly available in contact lens practice and are more accessible to clinicians. Despite their limited coverage of examination (usually up to 7 mm to 10 mm of chord diameter), they have the potential to provide direct and indirect information that might be relevant for ScCL fitting. It has been hypothesized that the anterior ocular sagittal height (OC-SAG) provided by corneal topographers could be of predictive value in estimating the sagittal height of the ScCL [12,13]. When trying to predict ScCL fitting from ocular surface

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parameters derived from corneal topography, Schornack et al [14] found weak correlations between them.

The present study aims to test this hypothesis using a commercial ScCL (Senso Mino Sclera, Procornea) and a commercial corneal topographer (Medmont E300, Victoria, Australia). Another hypothesis is that some of these measures might have predictive value in estimating the need for a toric peripheral geometry as well as the stabilization axis, as it is commonly observed in clinical practice that certain patterns of corneal astigmatism (i.e. limbus-to-limbus astigmatic corneas) seem to be related to the scleral shape. The main purpose was to analyze the relationship between OC-SAG parameters derived from corneal topography at different chord lengths and correlate that with the sagittal height of the ScCL (ScCL-SAG) that subjects were wearing. A secondary goal was to investigate whether corneal height asymmetry (differences in OC-SAG between flat and steep corneal meridians) and its orientation predicts the need for asymmetric/toric peripheral lens haptic area and corresponding stabilization of the lens.

2. Methods

2.1. Sample characteristics

This was a retrospective analysis involving patients with primary corneal ectasia, penetrating keratoplasty, post-surgical ectasia or regular corneas with high refractive errors (myopia $\geq 6.00D$; hyperopia $\geq 4.00D$ and/or astigmatism $\geq 2.00D$) fitted between October 2015 and March 2017. Following the recommendations of the Declaration of Helsinki, all subjects received information about the study before they agreed to participate and signed a consent form. The protocol of the study has been reviewed and approved by the Ethics Subcommittee for Life and Health Sciences of the University of Minho. A total of 175 eyes from 95 subjects were primarily recruited to participate in a study involving scleral-supported contact lens fitting. The initial 40 fittings (22 subjects) were excluded to eliminate the role of practitioner experience on the study outcomes (Macedo-de-Araújo, 2017, submitted for publication). Another 5 subjects (9 fittings) were excluded because of poor quality of the corneal topography acquisition due to highly distorted corneas. A total of 68 subjects (37 females, 31 males) with a mean age of 34 ± 10 years are included in this report. Of them, 10 wore lenses in one eye and 58 wore lenses in both eyes, representing a total of 126 eyes dispensed with ScCLs. The sample was analyzed according to the ocular condition that required the ScCL fitting: Group I (irregular corneas, $n = 92$ eyes) and Group II (high refractive error with regular corneas, $n = 34$ eyes). For some of the analysis, these groups were further subdivided: subgroup 1 (Subjects with primary ectasias without surgery); subgroup 2 (subjects with irregular corneas due to or with surgery – LASIK, ICRS, crosslinking); subgroup 3 (subjects with healthy corneas with corneal astigmatism $< 2.00 D$); subgroup 4 (subjects with healthy corneas with corneal astigmatism $> 2.00D$).

2.2. Scleral contact lens used and fitting method

The ScCLs were manufactured by Procornea (Eerbeek, The Netherlands) using Boston XO material (hexafocon A). All lenses were fitted empirically by the same practitioner. The initial trial lens was determined following manufacturers' guidelines, considering clinical features and the degree of severity of the corneal condition. The optimal ScCL should align evenly on sclera without conjunctival *blanching* and vault the entire corneal and limbal area with an ideal tear layer thickness of 100 to 200 μm after settling (2 h). All the lenses fitted had 8.20 mm back optic zone radius. The diameter ranged between 15.2 and 16.4 mm. The mean sagittal heights of the final ScCLs as provided by the manufacturer (mean between steep and flat scleral lens sagittal height - ScCL-SAG) used by the subjects at 1 month visit ranged from 3948 μm to 5428 μm (mean $4696 \pm 240 \mu m$), and the toricity of the landing zones ranged between T0 to T6 (in steps of 1), T0 being a lens

with no toric peripheral geometry (same geometry around the entire landing zone) and T6 having the maximum amount of toricity. The exact amount of toricity is not disclosed by the manufacturer. These ScCL parameters were compared to the corneal topographer outcomes listed below.

2.3. Corneal topography - data collection

2.3.1. Sagittal height parameters

Three repeated corneal topography measurements were performed with the Medmont E300 (Medmont International Pty Ltd., Victoria, Australia) and were analyzed with the Medmont Studio 6.1 in all eyes at the baseline appointment (prior to entering a prospective, dispensing clinical trial). Measurements of corneal sagittal height at two different chord lengths (10 mm and 12 mm) were analyzed for the flat and steep meridians of each individual eye. The estimated height (EHChord) parameter from the Medmont Studio 6.1 was also analyzed. This attribute provides the sagittal height of the anterior eye surface (OC-SAG) for a chord value set by the user. In this study, a chord equal to the diameter of the lens that the subjects were using was selected for each patient (between 15.2 mm and 16.4 mm) –i.e., if a subject was wearing a 16.4 mm lens, the EHChord attribute was analyzed to a chord value of 16.4 mm. Three parameters of estimated height (EH) provided by the topographer used were calculated for the particular chord diameter selected: EH 0-1 80°, which is the estimated height for the horizontal meridian for that specific chord length selected, EH 150-330°, and EH 30-210°. These data of OC-SAG for different zones and chord lengths were compared with the ScCL-SAG that subjects were wearing at 1 month of ScCL wear. Fig. 1 shows the relationship between OC-SAG (at 10 and 12 mm and EH-Chord parameter), ScCL-SAG and cornea-lens separation for different chord lengths.

2.3.2. ScCL stabilization

The ScCLs used in this study had marks indicating the flattest meridian of the lens in cases in which these lenses had some degree of toricity in the landing zone. The stabilization axis of the lens was measured *on-eye* during slit lamp examination. Following Visser et al's [15] methodology, a narrow slit beam was projected and oriented with the marks present in the lens periphery (indicating the flattest meridian), and the axis was obtained from the protractor incorporated in the slit lamp. The stabilization of the lens through the first day of lens wear was also analyzed for 103 of the 115 lenses that had some degree of toricity; the stabilization of the lenses was recorded 15 min after lens application and after more than 90 min of lens wear (mean time of wear: 126 ± 74 min). This indicated the rotational stability of the lens over time.

2.3.3. Corneal and scleral asymmetry

The differences in sagittal height between the steep and flat corneal meridians (corneal asymmetry) at 10 mm and 12 mm was determined to assess the possible relationship between corneal asymmetry and scleral asymmetry (which leads to the need to fit a lens with a toric landing zone geometry). These outcomes were analyzed separately according to the geometry of the ScCL landing zone that the subjects were wearing; 103 of the 115 lenses that had some degree of toricity in the periphery were analyzed. These lenses had marks in their periphery that indicate the flattest meridian of the lens haptic. This meridian aligned with the flat meridian of the sclera. To further compare corneal and scleral asymmetry, the axis of the flat corneal meridian and the axis of ScCL stabilization were compared among the different groups and subgroups. These measures were corrected for symmetry before they were analyzed.

2.4. Statistical analysis

Statistical analysis was conducted using SPSS v.24.0 (IBM Co, IL).

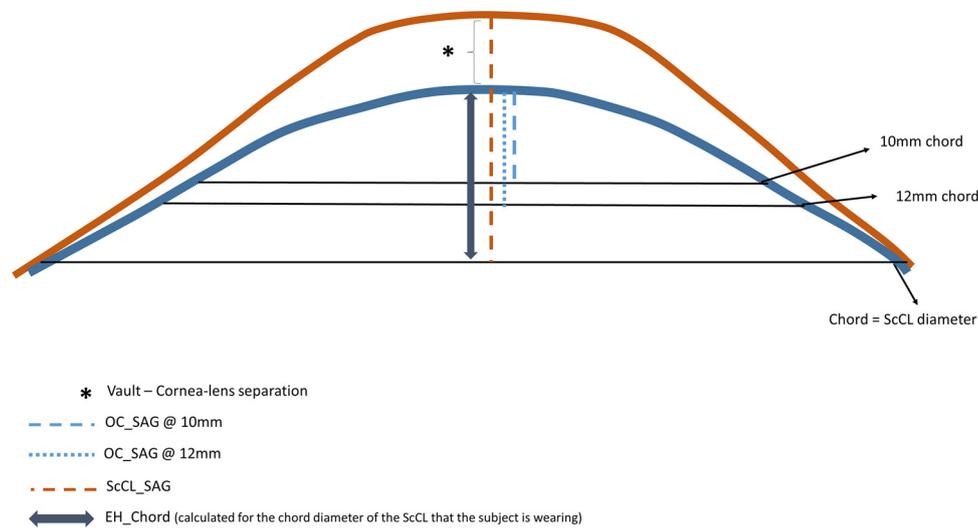


Fig. 1. Relationship between cornea-lens separation, ScCL-SAG and OC-SAG at 10 and 12 mm and EH-Chord parameter.

Table 1
Characteristics of the sample analyzed: results arranged by groups and subgroups.

	Total	Group I (Irregular Cornea)	Group II (Regular Cornea)	p
No. Subjects	68	50 (74%)	18 (26%)	–
No. Eyes Fitted	126	92 (73%)	34 (27%)	–
Gender	37 female (54%) 31 male (46%)	25 female (50%) 25 male (50%)	12 female (67%) 6 male (33%)	–
SG (No. Fittings)		SGL1: 53 (58%) SGL2: 39 (42%)	SGII.1: 8 (24%) SGII.2: 26 (76%)	–
Age (years)	34.09 ± 9.94 [range: 18 to 65]	35.74 ± 10.17 [range: 18 to 65]	29.50 ± 8.17 [range: 18 to 46]	< 0.050 +
SimK Flat (D)	44.01 ± 4.72 [range: 24.87 to 62.92]	44.42 ± 5.41 [range: 24.87 to 62.92]	42.89 ± 1.62 [range: 39.45 to 46.01]	< 0.050*
SimK Steep (D)	47.36 ± 5.06 [range: 29.83 to 65.38]	48.08 ± 5.69 [range: 29.83 to 65.38]	45.40 ± 1.2 [range: 42.87 to 46.01]	< 0.001*
Q Flat	–0.67 ± 0.50 [range: -2.89 to +0.43]	–0.75 ± 0.55 [range: -2.89 to +0.43]	–0.44 ± 0.18 [range: -0.86 to -0.11]	< 0.050 +
Q Steep	–0.20 ± 0.65 [range: -1.56 to 2.24]	–0.30 ± 0.69 [range: -1.56 to +2.24]	0.06 ± 0.43 [range: -0.32 to 1.64]	< 0.050*
OC-SAG (µm) – Flat meridian (10 mm)	1832 ± 160 [range: 1512 to 2376]	1866 ± 166 [range: 1512 to 2376]	1738 ± 92 [range: 1559 to 1916]	p < 0.001 *
OC-SAG (µm) – Steep meridian (10 mm)	1950 ± 138 [range: 1686 to 2395]	1965 ± 147 [range: 1686 to 2396]	1908 ± 101 [range: 1779 to 2185]	p < 0.05 *
OC-SAG (µm) – Flat meridian (12 mm)	2784 ± 279 [range: 2212 to 3552]	2839 ± 293 [range: 2212 to 3552]	2635 ± 165 [range: 2324 to 3015]	p < 0.001 *
OC-SAG (µm) – Steep meridian (12 mm)	3043 ± 275 [steep: 2546 to 4150]	3064 ± 292 [range: 2546 to 4150]	2986 ± 216 [range: 2604 to 3596]	p = 0.139 *
OC-SAG (µm) EHChord 0-180°	4162 ± 373 [range: 3479 to 7103]	4391 ± 539 [range: 3479 to 7103]	4193 ± 324 [range: 3515 to 4918]	p < 0.05 *
OC-SAG (µm) EHChord 150-330°	4250 ± 383 [range: 3525 to 6740]	4471 ± 538 [range: 3575 to 6740]	4307 ± 329 [range: 3525 to 5039]	p = 0.127 *
OC-SAG (µm) EHChord 30-210°	4251 ± 339 [range: 3619 to 8223]	4485 ± 610 [range: 3658 to 8223]	4289 ± 316 [range: 3619 to 4908]	p = 0.104 *
ScCL-SAG (µm) Flat meridian	4587 ± 254 [range: 3828 to 5307]	4604 ± 261 [range: 3841 to 5307]	4550 ± 233 [range: 3828 to 4883]	p = 0.242 *
ScCL-SAG (µm) Steep meridian	4803 ± 248 [range: 4069 to 5548]	4805 ± 244 [range: 4125 to 5548]	4795 ± 263 [range: 4069 to 5293]	p = 0.921 *

♀ female; ♂ male; SG – Subgroup; Q – corneal asphericity, OC-SAG – ocular sagittal height; ScCL-SAG – sagittal height of the scleral lens used; (+) Independent T-test, (*) Mann-Whitney U independent samples.

Normality of data distribution was analyzed with the Kolmogorov-Smirnov test in the different groups and with with Shapiro Wilk test within each subgroup. Pairwise comparison between groups or subgroups was done using the Independent sample t-test for normally distributed data and the Wilcoxon signed ranks test for non-normally distributed data. The level of statistical significance was set at $p < 0.05$.

3. Results

Table 1 shows the demographic data of the subjects enrolled in the present report including keratometric data, spherical equivalent refraction and best-corrected visual acuity with habitual correction (HC), best spectacle correction (BSC) and with ScCL and OC-SAG and ScCL-SAG parameters.

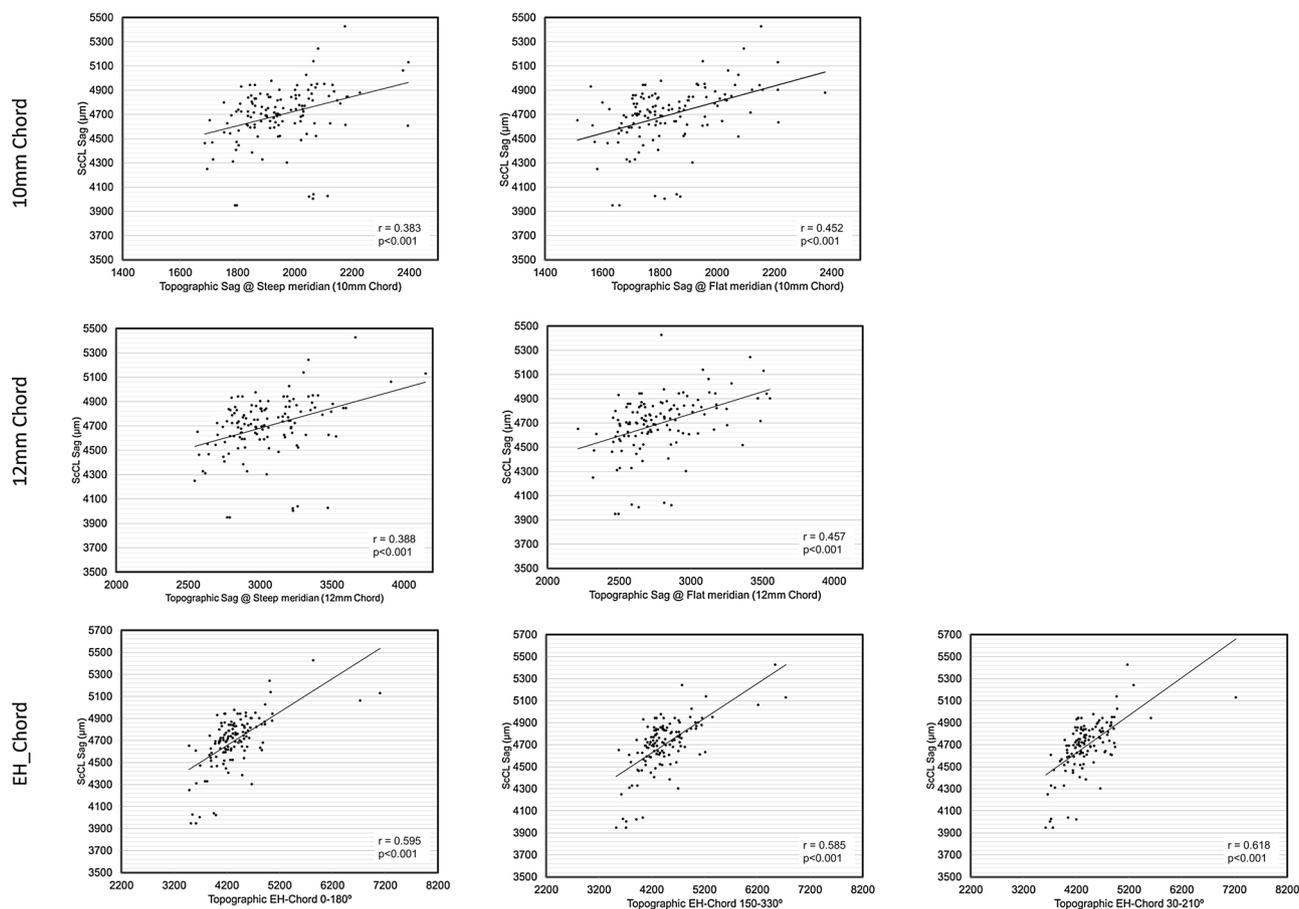


Fig. 2. Correlations between ScCL-SAG that subjects are wearing with different parameters derived from corneal topography with the Medmont E300. EH-Chord was taken for a chord equal to the diameter of the lenses that subjects were wearing (between 15.2 and 16.4 mm).

3.1. Relationship between OC-SAG and ScCL-SAG

The mean ScCL-SAG was $4696 \pm 240 \mu\text{m}$ (minimum $3949 \mu\text{m}$, maximum $5428 \mu\text{m}$). The diameters of the lenses fitted ranged from 15.2 mm to 16.4 mm; 108 lenses were 16.4 mm, 9 lenses were 16 mm, 3 lenses were 15.6 mm and 6 lenses were 15.2 mm. Table 1 also shows the mean OC-SAG values measured at different chord lengths for the 126 eyes analyzed (total and divided by groups). The OC-SAG values from Group I are statistically significantly higher than in Group II ($p < 0.05$, Wilcoxon), except for the sagittal height of the steep meridian at the 12 mm and EH Chords at $150\text{--}330^\circ$ and $30\text{--}210^\circ$. Fig. 2 shows the correlations between ScCL-SAG with different parameters derived from the Medmont corneal topographer. Spearman Rho values were < 0.500 for the correlations between OC-SAG and ScCL-SAG for 10 mm and 12 mm, indicating that the correlations for the flat meridian were higher than those for the steep meridian. The correlations were higher for the EHChord results, which represent the estimated height of the anterior ocular surface for a chord equal to the diameter of the lens that each subject was wearing (between 15.2 mm and 16.4 mm, depending on the lens that each subject was wearing).

The differences between the EHChord at different quadrants and the ScCL-SAG were $447 \pm 290 \mu\text{m}$, $391 \pm 260 \mu\text{m}$ and $389 \pm 360 \mu\text{m}$ for EH-Chord $0\text{--}180^\circ$, EH-Chord $150\text{--}330^\circ$ and EH-Chord $30\text{--}210^\circ$, respectively.

3.2. Relationship between corneal asymmetry and geometry of the ScCL landing zone

The vast majority – 115 lenses (91%) - of the 126 lenses fitted had some degree of toricity in the landing zone. Of those, data for 103 lenses

were recorded: 44 lenses with toricity of 1 (T1), 49 lenses with T2, 12 lenses with T3, 6 lenses with T4, 3 lenses with T3 and 1 lens with T6.

Table 2 shows the differences between the OC-SAG of the steep and flat meridians for the 10 mm and 12 mm chords, which represents the asymmetry between the principal corneal meridians. There was always a larger difference in the OC-SAG of the flat and steep meridian at 12 mm than at 10 mm in Group I ($p < 0.05$, Wilcoxon) and Group II ($p < 0.05$, *t*-test for pairwise samples). There were no statistically significant differences between Groups regarding the differences in both OC-SAGs at 10 mm and 12 mm ($p > 0.05$, *t*-test for independent samples or Mann-Whitney, depending on the distribution). In the Irregular Cornea Group (Group I), there was no relationship between the asymmetry in the OC-SAG at 10 mm and 12 mm and the toricity required in the landing zone (differences of $4 \mu\text{m}$ and $12 \mu\text{m}$ between the sagittal heights of subjects requiring toricity in the landing zone of 0–1 and 2–6). However, in the Healthy Cornea Group, it was observed that subjects requiring higher landing zone toricity (between T2–T6) also have greater corneal asymmetry (differences in the sagittal height of the principal corneal meridians) than those requiring lower toricity in the landing zone (T0 and T1); this is a difference of $36 \mu\text{m}$ for the 10 mm chord and $69 \mu\text{m}$ for the 12 mm chord.

To further explore this, the sample was divided into subgroups. Table 3 shows the differences in OC-SAG between the steep and flat meridians at 10 mm and 12 mm in the different subgroups. There was no relationship between the asymmetry in OC-SAG at 10 mm and 12 mm and the toricity of the landing zone required in the subgroups of the Irregular Cornea Group. For the subgroups of the Healthy Cornea Group, it was observed that subjects requiring larger amounts of toricity in the lens landing zone (between T2 and T6) had greater corneal asymmetries. The differences in the sagittal height of subjects requiring

Table 2
Corneal asymmetry (differences in OC-SAG between steep and flat meridians) for 10 mm and 12 mm and its relation with toricity of the landing zone.

T	Group I Irregular Cornea			Group II Regular Cornea		
	N	Corneal Asymmetry 10 mm (μm)	Corneal Asymmetry 12 mm (μm)	N	Corneal Asymmetry 10 mm (μm)	Corneal Asymmetry 12 mm (μm)
0	5	149 \pm 83 [range: 58 to 245]	298 \pm 152 [range: 124 to 484]	6	147 \pm 52 [range: 59 to 213]	313 \pm 128 [range: 79 to 460]
1	36	144 \pm 91 [range: 4 to 380]	326 \pm 210 [range: 5 to 786]	8	149 \pm 47 [range: 91 to 226]	309 \pm 97 [range: 203 to 468]
2	39	136 \pm 100 [range: 1 to 446]	318 \pm 229 [range: 18 to 867]	10	172 \pm 67 [range: 81 to 284]	372 \pm 173 [range: 113 to 713]
3	8	169 \pm 105 [range: 5 to 332]	305 \pm 276 [range: 43 to 883]	4	144 \pm 78 [range: 88 to 255]	292 \pm 163 [range: 175 to 522]
4	4	130 \pm 76 [range: 32 to 209]	262 \pm 175 [range: 29 to 408]	2	141 \pm 117 [range: 59 to 224]	317 \pm 198 [range: 177 to 458]
5	0	–	–	3	288 \pm 16 [range: 270 to 299]	587 \pm 60 [range: 518 to 626]
6	0	–	–	1	254	306
0–1	41	145 \pm 89 [range: 4 to 380]	323 \pm 203 [range: 5 to 786]	14	148 \pm 47 [range: 59 to 226]	311 \pm 107 [range: 79 to 468]
2–6	51	141 \pm 98 [range: 1 to 446]	311 \pm 230 [range: 18 to 311]	20	185 \pm 80 [range: 59 to 299]	380 \pm 173 [range: 113 to 713]
Difference (μm)		–4	–12		36	69

T – toricity of the landing zone (0 – no toricity, 6 – maximum toricity); N – number of subjects; Corneal Asymmetry – Difference between the sagittal height of the flat and steep corneal meridians; Difference – difference between the sagittal heights of subjects requiring peripheral spherical lens designs (no toricity) or lower toricity (T 0) and those requiring higher amounts of toricity in the periphery (T between 2 and 6).

lower (T0 or T1) or higher (between T2 and T6) landing zone toricity are greater in Subgroup 2–36 μm at 10 mm and 59 μm at 12 mm - in contrast to Subgroup 1–4 μm at 10 mm and 32 μm at 12 mm.

3.3. Corneal toricity vs. scleral toricity

3.3.1. Stabilization of ScCLs during wear

The mean stabilization angle of the ScCL right after insertion was 112 \pm 64° for right eyes and 55 \pm 55° for left eyes. After more than 90 min of lens wear, the mean lens stabilization angle was 113 \pm 65° for right eyes and 54 \pm 55° for left eyes. Fig. 3 shows the differences in lens stabilization for 103 of the 115 lenses that had some degree of toricity in the landing zone. The vast majority (67%) do not exhibit any rotation, 28.2% exhibited a rotation of 5°, 2.9% a rotation of 10° and 2% exhibited a lens rotation of more than 10° (1 subject with T3 had a lens that rotated 20°, and 1 subject with T2 had a lens that rotated 25°).

3.3.2. Relationship between corneal and scleral orientation

Fig. 4A shows the distribution of the mean differences between the axis of the flat corneal meridian and the axis of lens stabilization (that will align with the flat scleral meridian) for the total sample. The mean difference was 42 \pm 31°, with only 19% having a difference less than 10°. However, when dividing these results by subgroups (Fig. 4B), it was observed that the vast majority of subjects in Subgroup 4 (yellow bars) have a rotation less than 10°, in contrast with the other subgroups. The mean difference between the flat corneal meridian and the ScCL

stabilization meridian was 51 \pm 30° for Subgroup 1, 46 \pm 32° for Subgroup 2, 38 \pm 18° for Subgroup 3 and 12 \pm 14° for Subgroup 4.

The previous results of section 3.2 and the clinical judgment of the practitioner showed that when the corneal astigmatism was higher than 2.00D and had a limbus-to-limbus distribution (Subgroup 4), the sclera also seemed to have a toric shape with the same orientation, requiring back-toric periphery designs for correct alignment. Fig. 5 shows 4 cases of limbus-to-limbus corneal toricity with > 2.00D of astigmatism for which the axis of stabilization of the lens (that is on the flattest meridian) is very similar to the axis of the flat corneal meridian.

4. Discussion

Currently, the vast majority of ScCL fittings are based upon observations and estimation as well as the use of diagnostic lens sets (trial and error). One of the main difficulties is the limited information of the anterior ocular surface shape beyond the cornea. Corneal topography has shown to be important in fitting rigid contact lenses that land on the cornea, [16,17] but not for other types of lenses [18], including ScCLs [14]. Scleral topographers allow measurement of the amount and direction of scleral toricity and could aid the fitting process, complemented with customized fitting software [19,20]. OC-SAG is a key factor relevant in ScCL design and fitting and can be measured with different instruments, with minimal differences being found between the Medmont E300 and AS-OCT measurements (3732 \pm 159 μm and 3728 \pm 188 μm , respectively) [21].

Corneo-scleral transition is another anatomical factor that plays an important role in defining OC-SAG. [22] However, this cannot be assessed with standard corneal topography devices. When measuring OC-SAG at the 10 mm and 12 mm chord, it is basically the corneal shape that is being measured. However, ScCLs land only on the bulbar conjunctiva and underlying Tenon's capsule rather than on the sclera itself. It is a “spongy” surface, so the fitting could be unpredictable because the conjunctiva will be compressed differently under the pressure of the lens from patient to patient. Because of that, weak correlations were expected to be found regarding ScCL and corneal parameters. By observing Fig. 1, it is possible to observe weak correlations ($r < 0.5$) between ScCL_SAG and corneal parameters derived from corneal topography (at 10 and 12 mm chord analysis). However, moderate correlations were found between EHChord attributes and ScCL-SAG (Fig. 2), that was calculated for the diameter of the lens that subjects were wearing (between 15.2 and 16.4 mm). The mean differences between EHChord parameters and ScCL-SAG were 447 \pm 290 μm , 391 \pm 260 μm and 389 \pm 360 μm for EH-Chord 0–180°, EH-Chord 150–330° and EH-Chord 30–210°, respectively. All of these average values correspond approximately to the cornea-lens separation (vault) that the lenses should have upon application. However, there is a large variability factor that explains why this will not work satisfactorily in every patient. These results suggest that when a 16.4 mm ScCL fitting is required, it is possible to predict the best trial lens by measuring EH Chord for 16.4 mm and adding 447 μm if EH_Chord0–180° is analyzed or 389 μm if the EH_Chord30–210° is analyzed, for instance. Despite the easiness to use the horizontal direction to perform these measurements due to larger topography coverage, the correlation between ScCL SAG and EH_Chord30–210° was higher, so the author's recommend to use this value. A potential limitation of the study was the incorporation of different lens diameters into the analysis of EH-Chord outcomes. However, despite absolute values of OC_SAG could not be comparable as they were taken for the chord diameters equal to ScCL diameter, the differences between ScCL_SAG and OC_SAG are comparable, since they were analyzed for the same chord diameters.

It is known that the sclera is non-rotationally symmetric in nature and becomes more asymmetric with increasing distance from the limbus. [2,9,21,23,24] Because of this, ScCLs with a diameter larger than 15 mm often need to have back-surface toricity to align properly with the conjunctiva to avoid air bubbles and localized conjunctival

Table 3
Corneal asymmetry (differences in OC-SAG between steep and flat meridians) for 10 mm and 12 mm and its relation with toricity of the landing zone, analyzed by subgroups.

Lens Toricity	Group I Irregular Cornea						Group II Regular Cornea					
	SubGroup 1			SubGroup 2			SubGroup 3			SubGroup 4		
	N	Corneal Asymmetry 10 mm	Corneal Asymmetry 12 mm	N	Corneal Asymmetry 10 mm	Corneal Asymmetry 12 mm	N	Corneal Asymmetry 10 mm	Corneal Asymmetry 12 mm	N	Corneal Asymmetry 10 mm	Corneal Asymmetry 12 mm
0	2	113 ± 58 [range: 72 to 154]	257 ± 141 [range: 158 to 357]	3	173 ± 101 [range: 58 to 245]	324 ± 284 [range: 124 to 484]	1	59	79	5	165 ± 31 [range: 130 to 213]	360 ± 63 [range: 305 to 460]
1	18	136 ± 80 [range: 4 to 267]	314 ± 203 [range: 5 to 631]	18	152 ± 102 [range: 12 to 380]	339 ± 223 [range: 77 to 786]	3	102 ± 10 [range: 91 to 111]	210 ± 10 [range: 203 to 222]	5	178 ± 33 [range: 141 to 226]	368 ± 68 [range: 285 to 468]
2	25	133 ± 100 [range:18 to 446]	276 ± 207 [range:31 to 752]	14	141 ± 102 [range: 1 to 344]	392 ± 256 [range: 18 to 867]	2	115 ± 48 [range: 81 to 150]	242 ± 182 [range:113 to 370]	8	186 ± 65 [range: 95 to 284]	405 ± 166 [range: 202 to 713]
3	5	201 ± 125 [range: 5 to 332]	359 ± 343 [range: 43 to 883]	3	117 ± 25 [range: 90 to 140]	214 ± 110 [range: 133 to 340]	1	88	175	3	162 ± 84 [range: 89 to 255]	332 ± 174 [range: 180 to 522]
4	3	103 ± 67 [range: 32 to 165]	214 ± 178 [range: 29 to 214]	1	209	408	1	59	177	1	224	457
5	0			0			0			3	288 ± 16 [range: 270 to 299]	587 ± 61 [range: 518 to 626]
6	0			0			0			1	253	306
0;1	20	134 ± 78 [range: 4 to 267]	308 ± 196 [range: 5 to 631]	21	155 ± 100 [range:12 to 380]	337 ± 213 [range:77 to 786]	4	91 ± 23 [range: 59 to 111]	177 ± 66 [range: 79 to 221]	10	171 ± 31 [range: 130 to 226]	364 ± 62 [range: 285 to 468]
2;3;4;5;6	33	141 ± 103 [range:5 to 446]	283 ± 224 [range:29 to 883]	18	141 ± 92 [range: 1 to 344]	363 ± 237 [range:18 to 363]	4	94 ± 39 [range: 59 to 150]	209 ± 112 [range: 113 to 370]	16	207 ± 71 [range: 89 to 299]	423 ± 160 [range: 180 to 713]
Difference (µm)		-7	-26		-14	-27		-4	32		36	59

T – toricity of the landing zone (0 – no toricity, 6 – maximum toricity); N – number of subjects; Corneal Asymmetry – Difference between the sagittal height of the flat and steep corneal meridians; Difference – difference between the sagittal heights of subjects requiring peripheral spherical lens designs (no toricity) or lower toricity (T 0) and those requiring higher amounts of toricity in the periphery (T between 2 and 6); Subgroup 1 – Irregular cornea without surgery; Subgroup 2 – Irregular cornea due to surgery; Subgroup 3 – Healthy Cornea with corneal astigmatism < 2.00D; Healthy Cornea with corneal astigmatism > 2.00D.

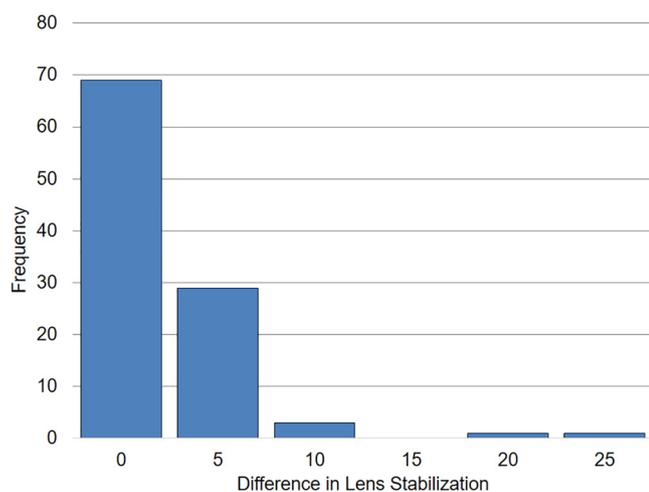


Fig. 3. Histogram showing the distribution of the differences (lens rotation, in degrees) in ScCL stabilization between 15 min after lens application and after 126 ± 74 min of lens wear.

blanching [15]. According to DeNaeyer et al, [6] only 5.7% of scleras have a spherical geometry (defined as less than 300 microns of difference in various meridians). In the present study, all of the ScCLs fitted had diameters larger than 15 mm and therefore, perhaps not surprisingly, 91% of the lenses fitted had some degree of toricity in the landing zone. Also, the ScCLs remained rotationally stable during the follow-up

exam conducted on the first day of lens wear (difference between 15 min and 126 min of wear), meaning that the lens did not rotate significantly during these period of lens wear. The vast majority of lenses (67%) did not exhibit any rotation, and 28% rotated up to 5°. These results are similar to those presented by López-Álcon et al, [25] who found stability in 87% of cases (with a maximum difference of 5°). In a different approach, Visser et al [15] concluded that ScCLs rapidly (within 4 to 6 s) return to their original positions even when rotated manually. It is important to have a constant stabilization of ScCLs on-eye, especially in cases in which a front-cylinder or special optical correction is needed.

According to the present study, the corneal asymmetry did not have a predictive power in helping to choose the best landing zone geometry of the ScCL in irregular corneas. However, those from Group II (healthy corneas) wearing lenses with a landing zone toricity larger than or equal to T2 have more than 36 µm (at 10 mm) and 69 µm (at 12 mm) of asymmetry compared to those requiring no or low toricity in the landing zone (T0 or T1). For that reason, subjects of Group II were further divided into two subgroups: one subgroup with low corneal astigmatism (subgroup 3) and the other subgroup with high corneal astigmatism (≥2.00D, subgroup 4). Table 3 shows that subjects of subgroup 4 have greater differences between the steep and flat meridians and that the amount of asymmetry is greater in those requiring toricity in the landing zone of ≥ T2. In fact, as has been shown in the last section of the results (Figs. 4B and Figure 5), when subjects have high corneal astigmatism, it seems that the sclera has the same geometry; however, it remains relatively unknown whether there is a

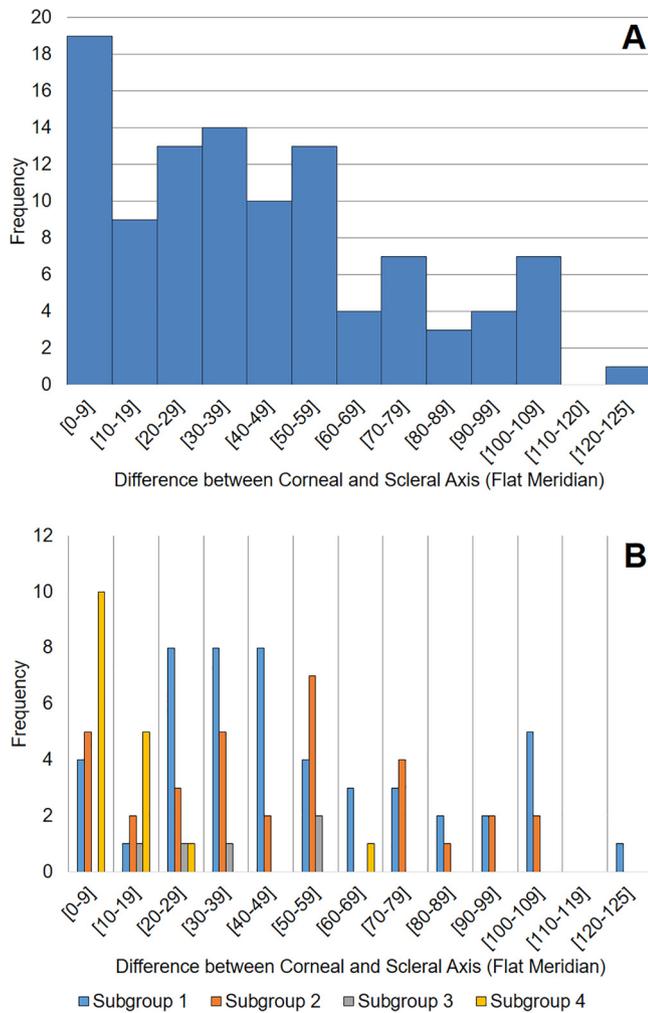


Fig. 4. Histogram showing the distribution of differences (in degrees) between flat corneal meridian and stabilization of the lens (that align with the flattest scleral meridian) in the total sample (A) and when divided by subgroups (B).

possible correlation between them. [7] A limitation of the present analysis is the fact that in the surgical group (subgroup 2) the corneal astigmatism is certainly affected by the surgical procedure, and therefore any relationship between corneal and scleral toricity is affected. This might explain why OC-SAG asymmetry derived from topography and lens landing zone toricity in post-surgical corneas are not related in the present sample. Conversely, as expected, in the regular corneas group, larger OC-SAG asymmetry measured with the topographer were associated with higher lens toricity, as seen on the last 3 rows of Table 2.

In this study, it was not possible to objectively measure the scleral

shape of the eyes with commercially available devices (such as scleral topographers or anterior segment OCT). However, it was possible to evaluate the axis of stabilization of the lens when a back-toric periphery design was necessary. Although it is well known that the sclera has an asymmetric shape in all quadrants [6], there are some studies concluding that there is no correlation between scleral and corneal shapes in most cases [26]. Nevertheless, some exceptions have already been observed: when the corneal toricity is congenital, it appears that corneal toricity could extend to the sclera [27]. Ritzmann et al [9] found that higher corneal astigmatism (> 2.00D) appeared to be more associated with scleral toricity compared to eyes with corneal astigmatism between 1.00D and 2.00D; in those eyes, only 27% had the same orientation of corneal and scleral astigmatism. The present study corroborates these early clinical observations. As Figs. 4 and 5 show, there is an apparent relationship between the scleral and corneal shapes in subgroup 4, as there are similar orientations on their flat meridians (mean difference of $12 \pm 14^\circ$). The axis of stabilization of the ScCL fitted was marked on the flattest meridian and was very similar to the axis of the flat corneal meridian. However, in the present study, this was seen only for the healthy corneas with limbus-to-limbus corneal shapes with high astigmatism – and it did not happen in ectatic or diseased corneas. López-Álcon et al [25] didn't find a relationship between corneal and scleral geometries – only in 27% of cases was there a similarity, with a maximum difference of 10° between them. The fact that corneal and scleral flat meridians are not at the same axis in irregular corneas might be related to the fact that the flatter axis determined by the topographer in such corneas must be quite variable and affected by the intrinsic pathological or surgical process.

5. Conclusions

In summary, OC-SAG estimated from EHChord attributes (taken for a chord equal to the diameter of the lens that each subject was wearing) were the best of the parameters analyzed for the prediction of ScCL-SAG. The mean difference of approximately $400 \mu\text{m}$ between the OC-SAG and the ScCL-SAG corresponds to the cornea-lens separation that these lenses should have right after lens application. However, there is a large variability factor that explains why this will not work satisfactorily in every patient. Corneal asymmetry (measured by means of the differences in OC-SAG between flat and steep corneal meridians) was shown to be a poor predictor for the need to fit a ScCL with toric peripheral geometry in irregular corneas. However, in cases of healthy corneas with high corneal astigmatism ($\geq 2.00\text{D}$), corneal asymmetry could help to predict whether the subject will need a toric landing zone design.

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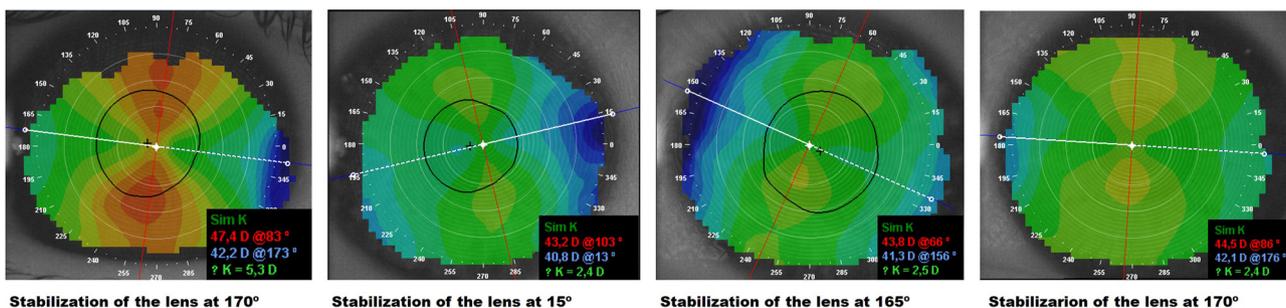


Fig. 5. Examples of corneal topographies (Medmont E300) from the sample of this study (healthy corneas) with limbus-to-limbus astigmatism. Notice that the axis of stabilization of the lens is similar to the axis of the flat corneal meridian.

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