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ORIGINAL RESEARCH

Patterns of Corneal Astigmatism in Eyes Post Myopic Laser Keratorefractive Surgery

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Purpose: In the absence of a measured posterior keratometry input, toric intraocular lens power formulae in patients with a history of myopic laser keratorefractive surgery (M-LVC) predict the posterior corneal astigmatism. These formulae assume that the posterior corneal curvature is essentially unchanged post M-LVC and hence its characteristics in this demographic of patients would be the same as virgin eyes. We aim to describe astigmatism measured by a swept-source optical coherence tomography biometer in such patients.
Patients and Methods: Retrospective consecutive case review of eyes with prior M-LVC, followed by subsequent cataract surgery. Pre-operative biometric data was collected using the IOLMaster 700 (Carl Zeiss Meditec). Magnitude and orientation of the steep and flat meridian of standard keratometry (SK), posterior keratometry (PK) and total keratometry (TK) were recorded. Relationships between corneal astigmatism, age, and gender were assessed. Statistical analysis was performed using linear regression, Mann Whitney *U*-test and Chi squared test.
Results: A total of 341 eyes (218 patients) were studied. Mean SK was 39.65D ± 2.16D. Mean PK was −5.82D ± 0.24D. Mean TK was 39.15D ± 2.34D. SK astigmatism (SKA) was predominantly vertical (57.8%, n = 197 eyes) with a mean magnitude of 0.85D ± 0.47D. Posterior corneal astigmatism (PCA) was predominantly vertical (91.5%, n = 312 eyes) with a mean magnitude of 0.29D ± 0.14D. TK astigmatism (TKA) was predominantly vertical (42.2%, n = 144 eyes) with a mean magnitude of 0.83D ± 0.47D. There was a positive correlation between magnitude of TKA with SKA and PCA ($P < 0.001$). A negative correlation between age and magnitude of SKA, PCA and TKA was noted ($P < 0.001$). No statistically significant relationship with gender was noted.
Conclusion: PCA orientation of post M-LVC eyes is similar to published data of virgin eyes. This reinforces the assumption made in toric intraocular lens power formulae that posterior corneal astigmatism in these eyes share the same characteristics as virgin eyes.
Keywords: LASIK, PRK, biometry, intraocular lens (IOL), IOL power calculation formulae, toric

Introduction

Uncorrected astigmatism is a significant cause of reduced visual acuity in patients.[1] Total corneal astigmatism (TCA) is contributed by both the anterior and posterior corneal surfaces. Traditional standard keratometry (SK) measurements estimate total cornea power by measuring the anterior corneal radius and applying a fixed keratometric index to account for posterior corneal power and corneal thickness. Newer technologies such a swept source optical coherence tomography (SS-OCT) have allowed direct measurements of the posterior cornea and corneal thickness, hence enabling a more accurate measurement of the true TCA.[2]

In patients with a history of myopic laser vision correction (M-LVC), ablation of the corneal stroma means that assumptions made utilising SK to determine the effective lens position and the refractive power of the cornea during intraocular lens (IOL) power calculations are no longer valid. Besides spherical correction, astigmatic correction is also important in this group of patients where the demand for spectacle independence post-cataract surgery is high. There are a few toric IOL power calculation formulae available to patients who had undergone laser keratorefractive surgery. In the absence of a measured posterior corneal curvature input, these formulae would have to predict the posterior corneal astigmatism (PCA) to determine the most appropriate intraocular lens power and orientation.[3–5] One assumption made is

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that the posterior corneal curvature is essentially unchanged post-laser keratorefractive surgery and hence the characteristics of the posterior cornea in this demographic of patients would be the same as virgin eyes. We aim to describe the patterns of astigmatism in this group of patients as there is little published data on this topic, hoping that our findings will aid in the understanding and further development of post M-LVC toric IOL power formulae.

Materials and Methods

We retrospectively reviewed the deidentified electronic medical records of 341 consecutive eyes (218 patients) with a history of M-LVC which were planned for cataract surgery at Tan Tock Seng Hospital, Singapore, between July 2017 and December 2022. Demographic data, type of M-LVC, laterality, and pre-operative biometric measurements were analysed. Pre-operative biometric measurements were obtained from the IOLMaster 700 (Carl Zeiss Meditec) (IOLM700), a swept-source OCT (SS-OCT) biometer. Routine biometric measurements such as axial length, anterior chamber depth, lens thickness, central corneal thickness, keratometry (standard, posterior and total) and corneal astigmatism (standard, posterior, and total keratometry) were collected. The magnitudes and orientations of corneal astigmatism were recorded. Based on keratometry values, eyes were classified as vertical (steep meridian between 60–120°), horizontal (steep meridian between 0–30 or 150–180°), or oblique (steep meridian between 31–59 or 121–149°). Further analysis was performed to assess the correlations between SK astigmatism (SKA), PCA and TK astigmatism (TKA). Analysis was also performed to assess correlations between corneal astigmatism and age, and gender. Statistical analysis was performed using Microsoft Excel (Version 16.84). Linear regression was used to assess the relationship between magnitudes of the various forms of astigmatism. Mann Whitney *U*-test was used to assess the relationship between astigmatism magnitude and gender. Chi Squared test was used to assess the relationship between astigmatism orientation and gender. A p value of <0.05 was considered statistically significant for this study. The study followed the tenets of the declaration of Helsinki and was approved by the Singhealth and National Healthcare Group institutional review boards for exemption due to analysis of dataset without identifiers The reference number for the study is 2021/2725.

Results

A total of 341 eyes of 218 patients were included, with ages ranging between 38 and 79 years and a median of 59 years. Majority had a history of myopic LASIK (n = 319 eyes), while a minority had a history of PRK (n = 22 eyes). There were more females (n = 191 eyes) than males (n = 150 eyes). As expected for our study population, axial lengths were longer than normal with a mean of 26.99 mm ± 1.84 mm (range; 23.19 to 34.57 mm). Mean anterior chamber depth measured was 3.32 mm ± 0.35 mm (range; 2.22 to 4.19 mm). Mean lens thickness was 4.38 mm ± 0.41 mm (range 3.07–5.93 mm). Mean central corneal thickness was 487 µm ± 43 µm (range 334 to 628 µm).

Mean SK was 39.65D ± 2.16D (range; 32.97 to 45.79D). SKA was predominantly vertical (57.8%, n = 197 eyes) and had a mean magnitude of 0.85D ± 0.47D (range; 0 to 2.42D). Centroid value of SKA was 0.38D with an axis of 92.1°. Mean posterior keratometry (PK) was −5.82D ± 0.24D (range; −5.20 to −7.13D). PCA was predominantly vertical (91.5%, n = 312 eyes) and had a mean magnitude of 0.29D ± 0.14D (range; 0 to 0.81D). Centroid value of PCA was 0.26D with an axis of 92.3°. Mean TK was 39.15D ± 2.34D (range; 31.76 to 45.83D). TKA was predominantly vertical (42.2%, n = 144 eyes) and had a mean magnitude of 0.83D ± 0.47D (range; 0 to 2.31D). Centroid value of TK astigmatism was 0.17D with an axis of 91.9° (Table 1 and Figure 1). For all forms of astigmatism, mean astigmatic power was highest when the steep meridian was oriented vertically (Figure 2).

There was a positive correlation between the magnitude of SKA and PCA (r = 0.394, $p < 0.001$). This was noted to be strongest when SKA was vertical (r = 0.465, $p < 0.001$), but less so when non-vertical (Oblique: r = 0.073, $p < 0.001$; Horizontal: r = 0.200, $p < 0.001$). Likewise, a positive correlation between the magnitude of TKA and PCA was also observed (r = 0.194, $p < 0.001$). This was also strongest when TKA was vertical (r = 0.299, $p < 0.001$) and less so when non-vertical (Oblique: r = 0.009, $p < 0.001$; Horizontal: r = 0.141, $p < 0.001$) (Figure 3).

We found PCA most commonly vertical in all orientations of SKA. Vertical PCA was seen most when SKA was vertical. Non-vertical PCA was seen most when SKA was non-vertical. A similar pattern was observed when comparing the orientations of PCA with TKA (Table 2).

Table 1 Summary of Corneal Astigmatism

Characteristic	SKA	PCA	TKA
Mean keratometry (D)	39.65 ± 2.16 (32.97 to 45.79)	−5.82 ± 0.24 (−7.13 to −5.20)	39.15 ± 2.34 (31.76 to 45.83)
Mean astigmatism (D)	0.85 ± 0.47 (0 to 2.42)	0.29 ± 0.14 (0 to 0.81)	0.83 ± 0.47 (0 to 2.31)
Centroid (D)	0.38 @ 92.1°	−0.26 @ 92.3°	0.17 @ 92°
Steep meridian vertical	197 (57.8%)	312 (91.5%)	144 (42.2%)
Steep meridian oblique	84 (24.6%)	25 (7.3%)	118 (34.6%)
Steep meridian horizontal	60 (17.6%)	4 (1.2%)	79 (23.2%)

Abbreviations: PCA, Posterior corneal astigmatism; SKA, Standard keratometry Astigmatism; TKA, Total keratometry astigmatism.

The magnitude of astigmatism tended to decrease with age. This relationship was stronger with PCA (r = −0.332, $p < 0.001$) compared to SKA (r = −0.155, $p < 0.001$) or TKA (r = −0.137, $p < 0.001$). PCA was most commonly vertical in all age groups, and we observed that there was a slightly greater proportion of vertical than horizontal or oblique PCA in older age groups. Likewise, SKA and TKA were most commonly vertical in all age groups as well. There was a lower proportion of horizontal SKA and TKA in older age groups noted (Figure 4). The chi-squared test demonstrated no statistically significant relationship between age group and orientation of all forms of astigmatism (SKA $p = 0.160$, PCA $p = 0.367$, TKA $p = 0.594$).

We did not observe any clear relationship between gender and astigmatism (Figure 5). Mann Whitney *U*-test demonstrated no statistically significant difference between genders for the magnitude of all forms of astigmatism (SKA $p = 0.351$, PCA $p = 0.894$, TKA $p = 0.391$). The chi-squared test demonstrated a statistically significant relationship between gender and SKA orientation, but not PCA or TKA orientation (SKA $p = 0.020$, PCA $p = 0.886$, TKA $p = 0.573$).

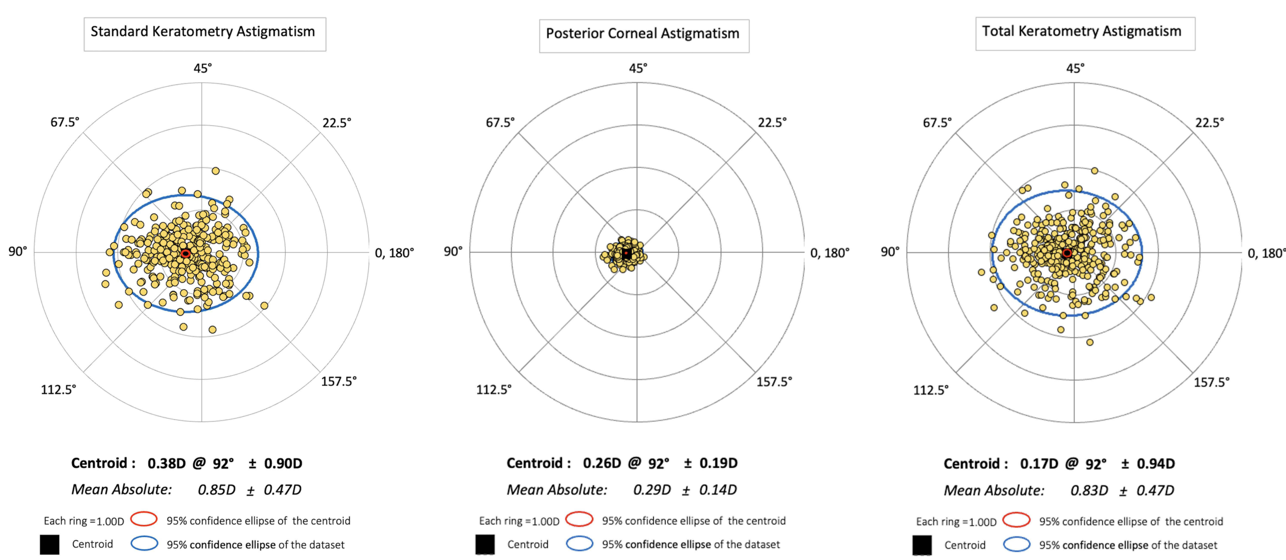

Figure 1 Double angled plots of standard keratometry astigmatism, posterior corneal astigmatism and total keratometry astigmatism.

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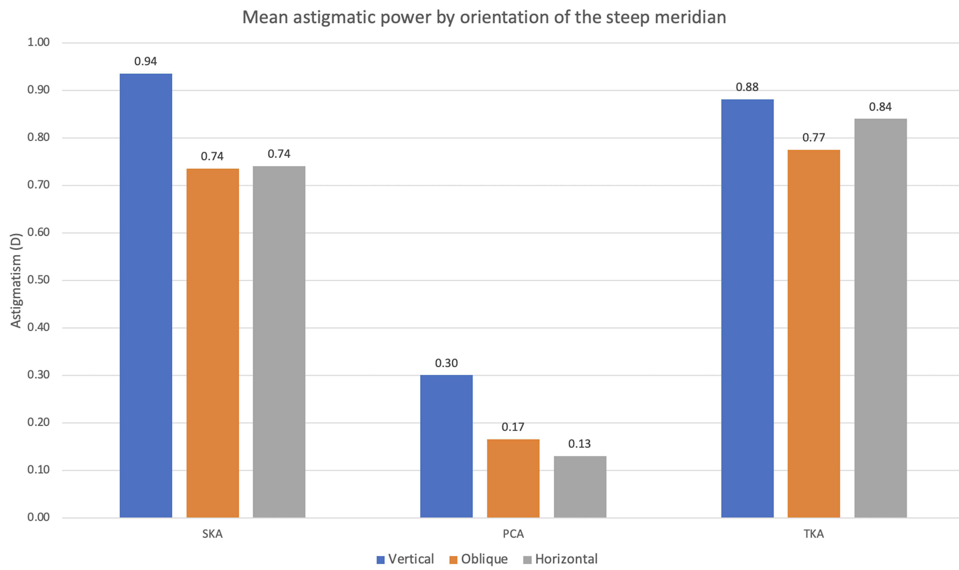

Figure 2 Mean astigmatic power by orientation of the steep Meridian.
Abbreviations: PCA, Posterior corneal astigmatism; SKA, Standard keratometry astigmatism; TKA, Total keratometry astigmatism.

Discussion

Our study describes the various forms of corneal astigmatism measured by SS-OCT biometer in a large cohort of patients with a history of M-LVC. We found that the magnitude and, more importantly, orientation of posterior corneal astigmatism in this cohort of patients were consistent with those in virgin eyes.

In our study, mean PK was −5.82D and mean PCA was 0.29D, which is in keeping with virgin eyes measured using the IOLM700 by Jin et al and LaHood et al who reported a mean PK of −5.90D and mean PCA of 0.24D in their cohorts, respectively.[6,7] The average magnitude of PCA measured using various devices in virgin eyes has been described to range widely between 0.24–0.78D.[7–10] This wide variation could be accounted for by various factors such as the measurement device, sample size, and age of the study cohorts.

For orientation, the steep meridian of PCA was vertical in 91.5% of our patients, which is in concordance with recordings from virgin eyes utilising modern imaging modalities, which report a range of 73.2–96.1%.[7,9,10] This is an important finding, as there are only a couple of toric IOL formulae optimised for such patients. To predict the posterior corneal curvature, these formulae assume that the posterior cornea is essentially unchanged post-laser refractive surgery, characteristics of PCA in this demographic would be the same as virgin eyes where PCA is predominantly vertically oriented.

Our analysis included TK data, which is of interest in this group of patients and has yet to be extensively described in this demographic. TK is a measurement unique to the IOLM700 intended to better represent total corneal power than SK. It utilizes anterior corneal measurements from telecentric keratometry, and posterior corneal and corneal thickness measurements from SS-OCT. The measurements are then optimized to allow usage by existing IOL formulae and lens constants provided by ULIB or IOLCon.[11] It has been demonstrated that in IOL power calculations for post M-LVC eyes, the use of TK led to greater predictive accuracy.[4,11] In patients post M-LVC, our study found TK to be lower than SK indicating that SK overestimates corneal power compared to TK. This is an expected finding given that TK should theoretically be a more precise account of the total corneal power than SK. This is because SK is a value derived from the measured anterior corneal radius and the keratometric index, where assumptions of the posterior corneal curvature of a virgin eye with a normal anterior to posterior corneal ratio are made. These assumptions are invalid in M-LVC patients.

Figure 3 Relationship between magnitudes of SKA/TKA and PCA.
Abbreviations: PCA, Posterior corneal astigmatism; SKA, Standard keratometry astigmatism; TKA, Total keratometry astigmatism.

Table 2 Distribution of PCA Orientations (Number and Percentage of Eyes) Across SKA and TKA Orientations

SKA or TKA Orientation	PCA Orientation	SKA – Number of Eyes (% of SKA Orientation)	TKA – Number of Eyes (% of TKA Orientation)
Vertical	Vertical	188 (95.4%)	135 (93.8%)
	Oblique	7 (3.6%)	7 (4.9%)
	Horizontal	2 (1.0%)	2 (1.4%)
Oblique	Vertical	73 (86.9%)	107 (90.7%)
	Oblique	11 (13.1%)	10 (8.5%)
	Horizontal	0 (0%)	1 (0.8%)
Horizontal	Vertical	51 (85%)	70 (88.6%)
	Oblique	7 (11.7%)	8 (10.1%)
	Horizontal	2 (3.3%)	1 (1.3%)

Abbreviations: PCA, Posterior corneal astigmatism; SKA, Standard keratometry Astigmatism; TKA, Total keratometry astigmatism.

When we compared the magnitudes of PCA with SKA we noted a positive correlation which was stronger when SKA was vertical compared to when it was non-vertical, and this was also a finding noted in virgin eyes.[7,9,12] We observed a similar relationship between the magnitudes of PCA and TKA in our patients as well.

LaHood et al reported a lower mean PCA magnitude in older age groups of virgin eyes. We also noted that the magnitude of PCA seemed to decrease with age and this was statistically significant. A scheimpflug imaging study of young myopic virgin eyes by Hu et al reported that the magnitude of vertically oriented PCA decreased with increasing age.[13]

We observed that the proportion of patients with vertical PCA at older age groups was slightly higher than younger age groups (except in the 30–39 years subgroup due to a very small sample size) but did not find this relationship statistically significant. Most studies of virgin eyes have instead reported a decreasing proportion of vertical PCA with older age.[7,10,12–14] A larger sample size incorporating a wider age range of eyes would be helpful in assessing if there is indeed a difference between post M-LVC and virgin eyes in this regard.

In terms of gender, we observed a higher magnitude of PCA in males than females – this was also a finding reported by a cohort of virgin eyes by Dunne et al.[15] However, we did not find any statistically significant relationship between gender and the magnitude of the various types of astigmatism we studied.

The strengths of our study include the large number of eyes measured in patients with M-LVC. To our knowledge this is the first detailed description of corneal astigmatism in this group of patients. There are some limitations to our study. Our cohort included only Asian eyes. While racial variation of the posterior corneal curvature has not been extensively studied, at least one study has shown ethnic differences in posterior corneal curvature.[16] Our study is also limited because it is a descriptive study. It would have been beneficial to have a control group of a similar study population but without keratorefractive surgery. Another limitation is that we included a higher number of post-LASIK patients compared to other forms of M-LVC such as PRK. We also did not have patients with newer modalities of M-LVC such as keratorefractive lenticule extraction. However, this reflects the proportion of patients undergoing cataract surgery currently, with less PRK and refractive lenticule extraction patients, and more LASIK patients. Our data is also concentrated mainly on eyes within an older age group as biometry data was collected from patients prior to cataract surgery.

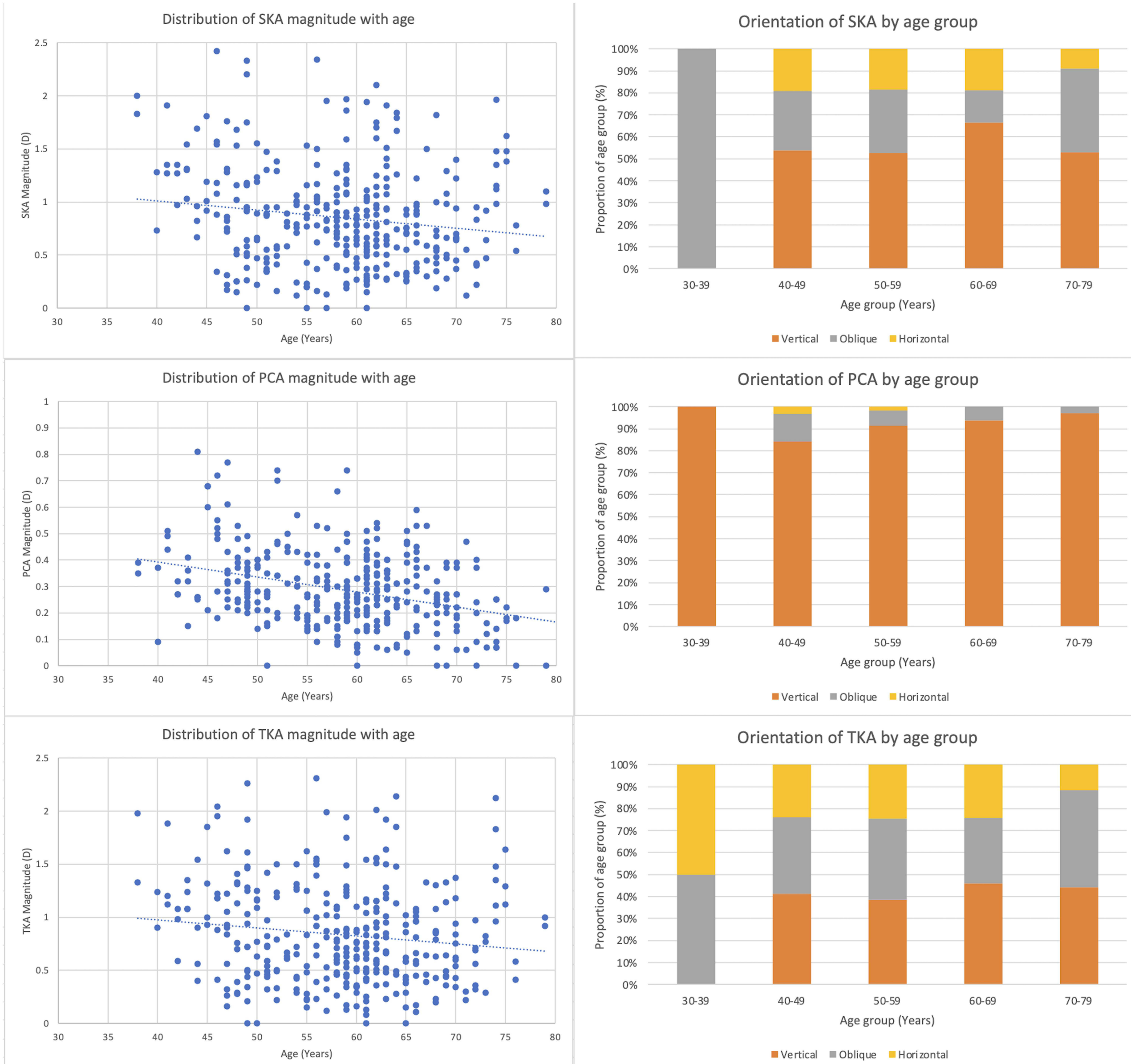

Figure 4 Relationship between type of astigmatism and age. Left: Distribution of astigmatism magnitude with age. Right: Distribution of astigmatism orientation by age group.
Abbreviations: PCA, Posterior corneal astigmatism; SKA, Standard keratometry astigmatism; TKA, Total keratometry astigmatism.

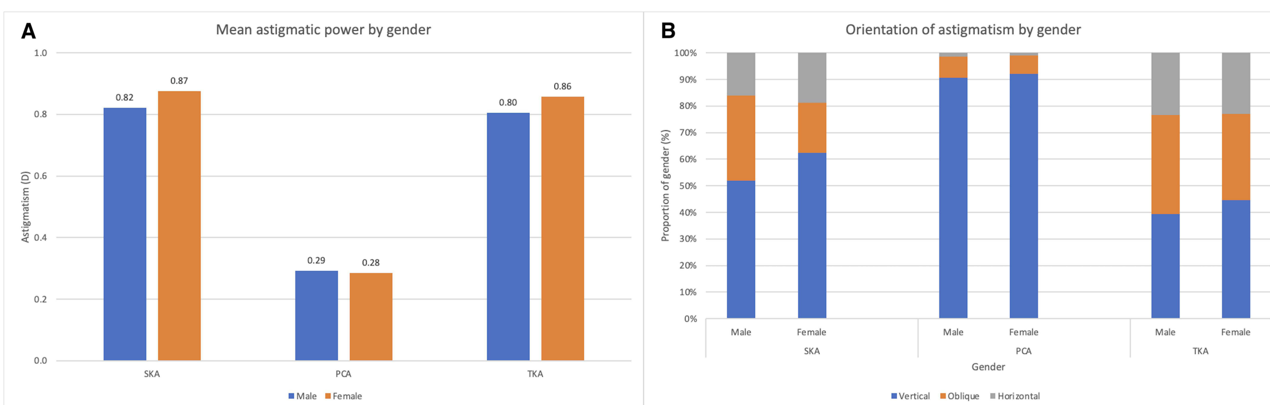

Figure 5 Relationship between type of astigmatism and gender. (**A**) Mean astigmatic power by gender. (**B**) Distribution of astigmatism orientation by gender.
Abbreviations: PCA, Posterior corneal astigmatism; SKA, Standard keratometry astigmatism; TKA, Total keratometry astigmatism.

Conclusion

In conclusion, our study demonstrates that the magnitude and orientation of PCA as measured by a SS-OCT biometer in eyes with a history of M-LVC were comparable to published data on virgin eyes. This reinforces a key assumption of modern post M-LVC toric IOL power formulae that posterior corneal astigmatism in post M-LVC and virgin eyes behave similarly. These findings contribute to the understanding and future development of post M-LVC toric IOL power formulae. Future studies with a more diverse racial and age demographic, along with a control group of similar eyes without a history of M-LVC, will enhance our understanding of the astigmatism in these patients.

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Disclosure

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