Posterior corneal astigmatism modifications after cataract surgery and its role on total corneal astigmatism

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Background: In recent years posterior corneal astigmatism and its effect on total corneal astigmatism has been studied, with research showing that this can impact total astigmatism. This study aims to ascertain if there is significant change in the posterior corneal astigmatism after cataract surgery and its impact on the total astigmatism.

Methods: Analysis of 76 eyes that underwent cataract surgery with monofocal intraocular lens implantation. Corneal topography was performed with Pentacam (OCULUS®) pre- and post-operatively. Total corneal astigmatism was calculated with the algorithm of vergence tracing. We compared preoperative and postoperative changes in the magnitude and axis differences of anterior corneal curvature astigmatism, posterior corneal curvature astigmatism and the calculated total corneal astigmatism. We calculated the correlation between the total preoperative astigmatism and the difference between total corneal astigmatism and anterior corneal astigmatism.

Results: The mean preoperative and postoperative posterior astigmatism was 0.31±0.02 D, showing no significant differences before and after surgery (P=0.989). Statistically significant differences between the calculated total corneal astigmatism and anterior corneal astigmatism were registered preoperatively and postoperatively in the with-the-rule anterior (WTR) corneal astigmatism (P=0.004, P<0.0001); against-the-rule (ATR) anterior corneal astigmatism (P<0.0001, P<0.0001) and in the oblique (P=0.026, P=0.019) subgroups. The posterior corneal astigmatism and the total corneal astigmatism correlated positively with the differences between the total corneal and anterior corneal astigmatism (R=0.378, P=0.001).

Conclusions: There were statistically significant differences between the magnitude of the total astigmatism and anterior corneal astigmatism, underlining the impact of posterior corneal astigmatism. A positive correlation between the preoperative posterior astigmatism and the difference between the total corneal and the anterior corneal astigmatism suggests a specially relevant role of posterior corneal astigmatism when evaluating patients with higher degrees of astigmatism.

Keywords: Astigmatism; cataract surgery; intraocular lens; posterior corneal curvature; total corneal astigmatism

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Introduction

Corneal astigmatism occurs frequently after cataract surgery, with 15% to 50% of cataract patients exhibiting 1 diopter (D) to 2 D corneal astigmatism after surgery, according to the literature (1-4). Surgical advances in the latest years with the development of toric intraocular lenses have allowed surgical correction of astigmatism after cataract surgery, resulting in better outcomes regarding the quality of uncorrected vision (5-6), yet a considerable number of patients still presents with higher than predicted residual cylinder values (7-11). Though several aspects are implied in post-surgical astigmatism (11), one of the factors that has been studied recently is related to the estimation methods of total corneal astigmatism (8-11). Traditionally, total corneal astigmatism is estimated based on the anterior keratometric values, assuming that the ratio between the anterior and posterior corneal curvatures is fixed, and therefore estimating the contribution of the posterior corneal astigmatism on total corneal astigmatism (8). Scheimpflug technology, based corneal topographers have permitted an easy evaluation of the anterior and posterior corneal surfaces (12-15). Therefore, studies that address the effect of posterior corneal astigmatism on total corneal astigmatism, and its impact on post-surgical astigmatism have arisen (8-11,16-18). Koch *et al.* [2012] who studied a population of 715, obtaining more accurate estimates of total corneal astigmatism by incorporating posterior keratometric astigmatism, concluded that the effect of posterior corneal astigmatism on total astigmatism estimation leads to overcorrection in eyes that have with-the-rule (WRT) anterior corneal astigmatism and undercorrection in eyes that have against-the-rule (ATR) anterior corneal astigmatism (8). Other works have found similar results highlighting the relevance of estimation errors of total corneal astigmatism when the posterior corneal surface is not considered (2,9-11,16,17).

Our study intends to validate in our population, the effect of posterior corneal astigmatism on total corneal astigmatism in an older population submitted to standard cataract surgery and to determine if the pre-operative magnitude of anterior corneal astigmatism is correlated with the difference between calculated total corneal astigmatism and anterior corneal astigmatism.

Methods

This study analyzed retrospectively 76 eyes of 69 patients that underwent cataract surgery with monofocal intraocular lens implantation through a 2.75 mm clear cornea incision on the steepest meridian by the same surgical team between June and December of 2016. The study was conducted in accordance with the ethical standards of the institutional research committee and the Declaration of Helsinki. Informed consent was obtained from all participants. Before surgery the patients underwent a standard ophthalmologic examination and corneal topography was performed with the Pentacam (OCULUS®) before and after surgery (two months post-operatively). Inclusion criteria included: (I) good-quality Pentacam scans (labeled as "OK" by the software); (II) no previous ocular trauma or surgery; (III) no corneal or other ocular diseases; (IV) no surgical complications or posterior capsule opacification, and (V) no contact lens use within 2 weeks of the dual corneal topography measurements.

All patients underwent Pentacam corneal topography by the same experienced examiner and measurements were made in automatic mode. Excellent repeatability has been attributed to the corneal curvature measurements obtained by this device (19).

Corneal central thickness and keratometry of the anterior and posterior corneal surface values were obtained from Pentacam measurements. We calculated the total corneal astigmatism applying the algorithm of vergence tracing before and after surgery as previously reported in the literature (9,16,20,21). We applied a standard conversion method for left eyes, according to the findings by Eydelman *et al.* (22). Flipping of the cylinder axes around the vertical axis was performed to avoid errors related to cyclotorsion while analyzing the average data from right and left eyes, with the new axis for left eyes being equal to 180º minus the original axis (16,22).

The astigmatism was classified according to the spatial orientation of the anterior steep meridian as WTR (60–119º), ATR (0–29º or 150–179º) or oblique (30–59º or 120–149º). Pre-operative total corneal astigmatism magnitude was also considered as we classified our patients as having ≤0.75, 0.75–1.50 and ≤1.50 D.

We performed a comparative analysis between the preoperative and postoperative changes of the anterior, posterior and total corneal astigmatism; as well as between the preoperative and postoperative axis changes. We analyzed these data both in our population of 76 eyes, as well as in each subgroup of astigmatism (WTR, ATR and oblique), since previous work from Koch *et al.* [2012] pointed at different magnitudes for the effect of posterior corneal astigmatism on total astigmatism estimation when considering WTR anterior or ATR anterior corneal astigmatism (8).

Statistical analysis

We compared the preoperative and postoperative changes in the average magnitude and axis of the anterior corneal curvature astigmatism, posterior corneal curvature astigmatism and the calculated total corneal astigmatism

Table 1 Comparison of the preoperative and postoperative corneal astigmatism magnitude (n=76)

Astigmatism subgroup	Preoperative		Postoperative	
	Mean ± SD	Range	Mean ± SD	Range
Anterior astigmatism	0.99±0.08	0.10–3.40	0.96±0.079	0.10–3.40
Posterior astigmatism	0.31±0.02	0.00–0.70	0.31±0.02	0.00–0.90
Total corneal astigmatism	1.28±0.10	0.11–3.93	1.29±0.10	0.04±3.99

D, diopters; SD, standard deviation.

Table 2 Comparison of the preoperative and postoperative corneal astigmatism axis differences

Corneal astigmatism axis differences	Compared axis measurements	Mean	SD	P value
Preoperative	Anterior corneal – total corneal	0.13	88.29	0.990
	Posterior corneal – total corneal	–9.04	61.14	0.201
Postoperative	Anterior corneal – total corneal	–17.95	83.76	0.066
	Posterior astigmatism – total corneal	–14.38	64.49	0.056

SD, standard deviation.

with the paired *t*-test, except when analyzing the oblique astigmatism population where we used the Wilcoxon test, given that this subpopulation was not normal.

Correlation between the magnitude of preoperative astigmatism values (anterior, posterior and total corneal astigmatism) and the difference between total corneal astigmatism and anterior corneal astigmatism was determined with the Pearson correlation test. Statistical analysis was conducted with the IBM SPSS Statistics 2.2 software (SPSS, Inc, Chicago, IL, USA).

Results

We studied 76 eyes of 69 patients, with a mean age of 75.11±7.82 years and a slight female predominance (57.97% *vs.* 42.03%). We verified an approximately equal distribution between right and left eyes.

Statistical analysis without division in subgroups

We summarize the preoperative and postoperative mean magnitude of the anterior, posterior and total corneal astigmatism on *Tables 1,2*. The mean preoperative and postoperative values of keratometric posterior astigmatism were 0.31±0.02 D. There were no statistically significant differences between the magnitude of the posterior corneal curvature astigmatism before and after surgery (P=0.989), nor between the preoperative and postoperative magnitude of anterior corneal astigmatism (P=0.583) and total corneal astigmatism (P=0.897). When comparing the difference between the anterior corneal astigmatism and the total corneal astigmatism a statistically significant result was observed in the preoperative (P<0.0001) and postoperative measurement (P<0.0001).

Regarding the axis of the astigmatism there were no statistically significant results between the preoperative and postoperative axis measurements of the corneal anterior surface (P=0.051), posterior corneal surface (P=0.914) and total corneal astigmatism (P=0.437), as summarized in *Tables 1,2*. The mean difference between the axis of the anterior corneal surface and the total corneal astigmatism was 0.13±88.29 preoperatively and 17.95±83.76 postoperatively. These changes were not statistically significant (P=0.990 and P=0.066 respectively). When calculating the difference between the posterior cornea and the total corneal astigmatism we also did not find any differences preoperatively (P=0.201) and postoperatively (P=0.056).

Subgroup analysis according to the astigmatism classification

We classified our population in three subgroups according to the orientation of the steep meridian and analyzed the magnitude and axis changes of the anterior, posterior and total corneal astigmatism in each group. ATR astigmatism was found in 52.63% of our population (n=40), followed by WTR astigmatism (n=22) and oblique astigmatism (n=14), as summarized in *Table 3*.

WTR astigmatism

A statistically significant difference between the anterior corneal astigmatism and the total corneal astigmatism was found preoperatively (P=0.004) and postoperatively (P<0.0001), and the mean magnitude of this difference was 0.25±0.37 and 0.33±0.36 D, respectively (*Table 4*, *Figure 1*).

Table 3 Preoperative astigmatism classification (n=76). The anterior corneal surface and the posterior corneal surface were classified regarding the orientation of the steepest meridian. Additionally, estimated total corneal astigmatism magnitude was stratified in three subgroups according to corneal power

Classification	Number
Anterior corneal steep meridian orientation	
WTR astigmatism	22
ATR astigmatism	40
Oblique astigmatism	14
Posterior corneal steep meridian orientation	
WTR astigmatism	56
ATR astigmatism	11
Oblique astigmatism	9
Total corneal astigmatism power magnitude (D)	
<0.75	21
0.75–1.50	37
>1.50	18

WTR, with-the-rule; ATR, against-the-rule; D, diopters; SD, standard deviation.

No significant changes were observed when comparing the differences between the preoperative and postoperative measurements of anterior corneal astigmatism (P=0.717), posterior corneal astigmatism (P=0.623) and total corneal astigmatism (P=0.696).

When comparing the preoperative and postoperative axis differences of the anterior corneal astigmatism, posterior corneal astigmatism and total corneal astigmatism; no statistically significant changes were observed.

ATR astigmatism

We found a statistically significant difference between the total corneal astigmatism and the anterior corneal astigmatism both preoperatively (P<0.0001) and postoperatively (P<0.0001). The mean magnitude of this difference was 0.35±0.21 and 0.36±0.26 D, respectively (*Tables 4,5*, *Figure 2*).

When analyzing the preoperative and postoperative measurements of the anterior corneal astigmatism, posterior corneal astigmatism and total corneal astigmatism, no statistically significant differences were found (P=0.443; P=0.536 and P=0.583).

Regarding the astigmatism axis changes, no statistically significant changes were observed when comparing the preoperative and postoperative measurements of the anterior, posterior and total corneal astigmatism axis.

Oblique astigmatism

We observed a statistically significant difference when comparing the magnitude of the anterior corneal astigmatism and the total corneal astigmatism both preoperatively (P=0.026) and postoperatively (P=0.019) and the mean magnitude of these changes was 0.17±0.23 D and 0.24±0.30 D, respectively. When comparing the preoperative and postoperative magnitude of the anterior, posterior and total corneal astigmatism, no statistically

Table 4 Corneal astigmatism power magnitude distribution in subgroups (n=76)

Astigmatism subgroup	Preoperative (mean ± SD)			Postoperative (mean ± SD)		
	WTR	ATR	Oblique	WTR	ATR	Oblique
Anterior astigmatism	1.08±0.15	1.02±0.12	0.74±0.09	1.06±0.18	0.96±0.11	0.80±0.08
Posterior astigmatism	0.36±0.04	0.29±0.03	0.31±0.04	0.34±0.04	0.31±0.03	0.28±0.06
Total corneal astigmatism	1.34±0.19	1.37±0.14	0.91±0.14	1.39±0.23	1.32±0.13	1.04±0.14

WTR, with-the-rule; ATR, against-the-rule; D, diopters; SD, standard deviation.

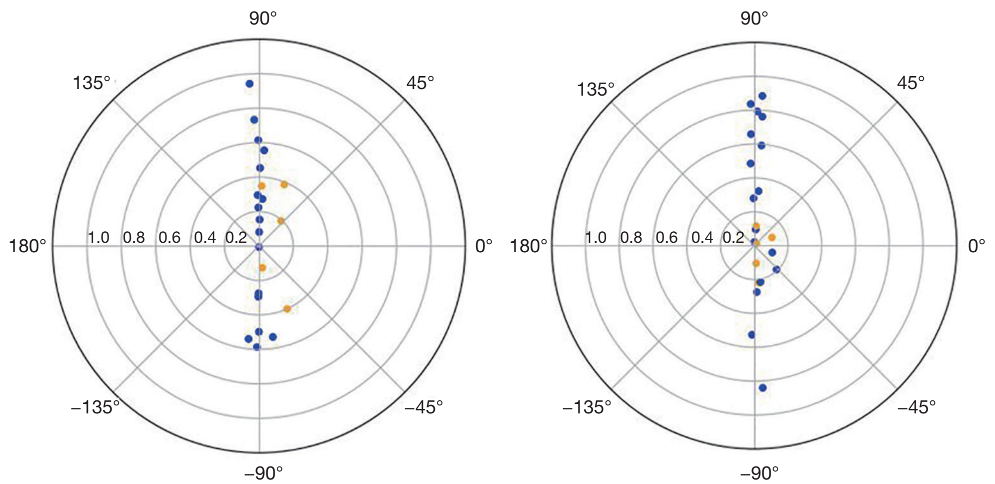

Figure 1 Polar plot for WTR astigmatism, subgroup showing the differences between the total corneal astigmatism and the anterior corneal astigmatism both preoperatively (left graphic) and postoperatively (right graphic). Blue and orange dots correspond to positive and negative differences in magnitude respectively. WTR, with-the-rule.

Table 5 Total corneal astigmatism and anterior corneal astigmatism difference (n=76)

Astigmatism subgroup	Preoperative			Postoperative		
	Mean ± SD	95% CI	P value	Mean ± SD	95% CI	P value
WTR	0.25±0.37	0.09–0.42	0.004	0.33±0.36	0.17–0.49	0.000
ATR	0.35±0.21	0.29–0.42	0.000	0.36±0.26	0.28–0.45	0.000
Oblique	0.17±0.23	–	0.026	0.24±0.30	–	0.019

WTR, with-the-rule; ATR, against-the-rule; D, diopters; SD, standard deviation.

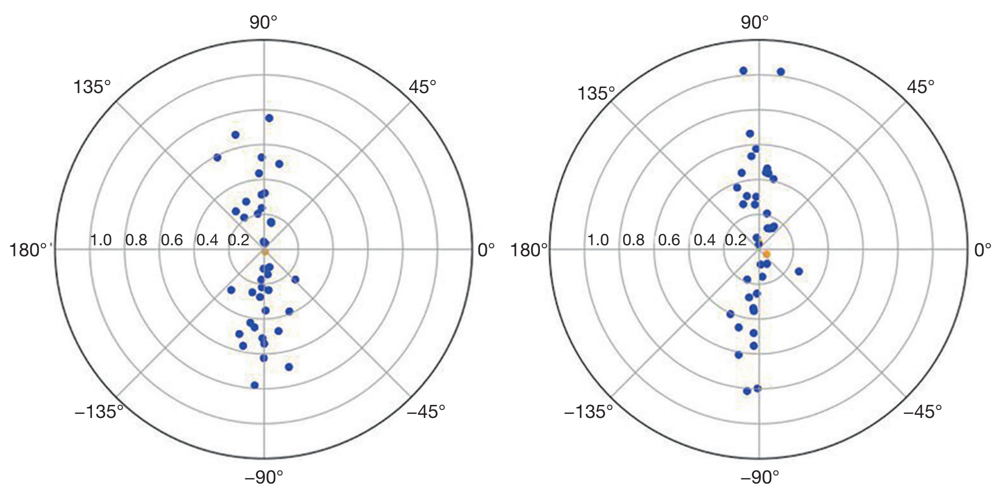

Figure 2 Polar plot for ATR astigmatism subgroup showing the differences between the total corneal astigmatism and the anterior corneal astigmatism both preoperatively (left graphic) and postoperatively (right graphic). Blue and orange dots correspond to positive and negative differences in magnitude respectively. ATR, against-the-rule.

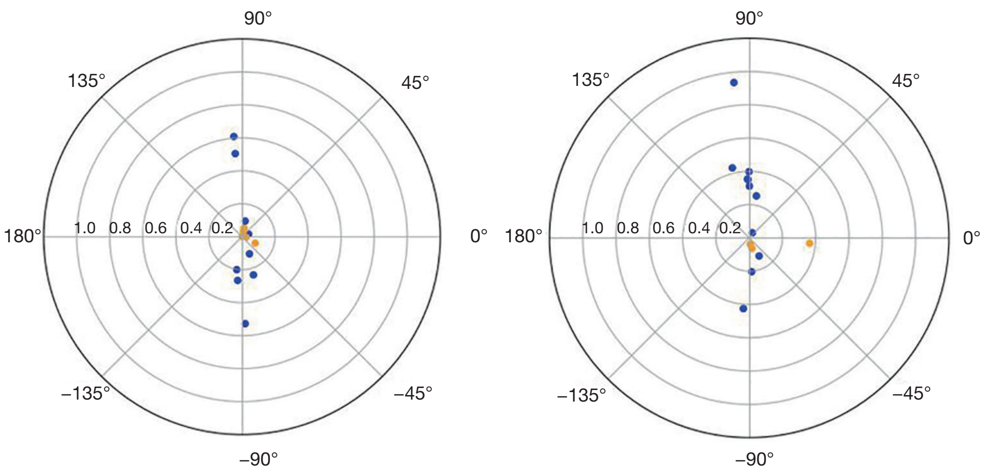

Figure 3 Polar plot for oblique astigmatism subgroup showing the differences between the total corneal astigmatism and the anterior corneal astigmatism both preoperatively (left graphic) and postoperatively (right graphic). Blue and orange dots correspond to positive and negative differences in magnitude respectively.

significant differences were found (P=0.363; P=0.496; P=0.551, respectively) (*Tables 4,5*, *Figure 3*).

No statistically significant differences were found, regarding axis changes in the anterior, posterior or total corneal astigmatism.

Correlation analysis between the magnitude of astigmatism and the difference between anterior and total corneal astigmatism

We found a moderate correlation between the magnitude of the preoperative total corneal astigmatism and the difference between postoperative total corneal astigmatism and anterior corneal astigmatism (R=0.378, P=0.001). A similar correlation was found between the magnitude of the posterior corneal surface astigmatism and the postoperative total corneal astigmatism and anterior corneal astigmatism (R=0.378, P=0.001).

The analysis of the correlation between the magnitude of the preoperative anterior astigmatism and the difference between the postoperative total corneal astigmatism and the anterior corneal astigmatism also revealed a positive correlation (R=0.316, P=0.005), but of lower strength.

Discussion

Our study intended to ascertain if there was a significant change on posterior corneal astigmatism after cataract surgery, if estimated total corneal astigmatism based on anterior and posterior corneal surfaces differed significantly from anterior corneal astigmatism and finally to determine if there is a positive correlation between preoperative magnitude of corneal astigmatism and the difference between corneal total astigmatism and anterior astigmatism.

Analysis of the population without subgroup division according to the astigmatism classification verified that there was very little variability in posterior corneal astigmatism after surgery, showing no statistically significant changes when compared to the preoperative values (P=0.989). The mean posterior corneal astigmatism was 0.31±0.02 D both pre and postoperatively, a result that is consistent with previous works (8,9,16) that have reported a posterior corneal power from 0.26 to 0.78 D and Koch *et al.* having reported a mean power 0.30 D with 5% of the eyes over 0.50 D (8). We also found that there was little variability between the preoperative and postoperative values of anterior astigmatism and total corneal astigmatism, which possibly reflects a low surgically induced astigmatism by phacoemulsification surgery in our patients, concordant with the literature (23).

Koch *et al.* [2012] demonstrated in a 715 eyes study that the effect of posterior corneal astigmatism on total astigmatism estimation leads to overcorrection in eyes that have WTR anterior corneal astigmatism and undercorrection in eyes that have ATR anterior corneal astigmatism (8). Other works have found similar results highlighting the relevance of these estimation errors (2,9-11,16,17). Since these reports have shown that the orientation of the steeper meridian has a significant role in these estimation errors, we decided to divide our population likewise and study the magnitude and axis behavior of anterior, posterior and total corneal astigmatism in these subgroups.

To ascertain if the posterior corneal astigmatism has an impact on total corneal astigmatism, we compared estimated total corneal astigmatism and anterior surface astigmatism. We found a statistically significant result in the preoperative (P<0.0001) and postoperative measurements (P<0.0001), reflecting the relevance of incorporating the posterior corneal surface to obtain a more accurate estimative of the total corneal astigmatism (2,8,9-11,16,17). Regarding the axis of the astigmatism no statistically significant results were found when comparing preoperative and postoperative axis measurements of the anterior, posterior and total corneal surface. We also did not find any differences between the axis of the anterior surface and total corneal axis, as well as between the posterior surface and total corneal axis, neither preoperatively no postoperatively. Although it did not reach statistical significance, we can observe that the magnitude of the axis difference increases in the postoperative measurements.

We found a predominance of ATR anterior astigmatism, which is consistent with our older population, since a gradual shift from WTR to ATR astigmatism has been described with aging (8,9,16,24,25).

In all subgroups we found a statistically significant difference between the magnitude of anterior corneal astigmatism and total corneal astigmatism. This result validates the importance of incorporating posterior corneal astigmatism to achieve a better estimation of total corneal astigmatism. The significantly narrower 95% confidence interval of the preoperative and postoperative differences in the ATR group when compared to the WTR group suggests that the changes we observed, although evident in all subgroups, were more consistent in ATR astigmatism than in WTR and oblique astigmatism. This may be explained by differences in the number of eyes in each subgroup, with a larger proportion of eyes with ATR astigmatism. In our study the magnitude of total corneal astigmatism was higher than the anterior corneal surface in all subgroups, which is not concurrent with previous results in the literature, since it has been described that in eyes with ATR anterior astigmatism, ATR astigmatism generated by the posterior corneal surface will vectorially sum to the anterior corneal power, therefore resulting in a higher total corneal astigmatism when compared to keratometric anterior corneal astigmatism, while in eyes with WTR astigmatism the reverse effect is observed. Also, when analyzing astigmatism axis changes in WTR, ATR and oblique subgroups, we found no statistically significant differences in preoperative and postoperative changes when comparing both posterior and anterior corneal astigmatism with the estimated total corneal astigmatism. These conflicting results may arise from limitations in the study design but given that the magnitude of total corneal astigmatism results from the vectorial sum of anterior and posterior surface vectors and the fact that our study shows a mean difference between total corneal astigmatism and anterior corneal astigmatism of around 0.30 D, even relatively low changes in the axis magnitude may play a role in these differences. Additionally, in our population the posterior corneal surface steeper meridian was oriented vertically in 73.68% of the eyes, a percentage that was considerably lower than previous studies such as the 86.6% reported by Koch *et al.* (8) or the 96.1% reported by Ho *et al.* (15).

Finally, we found a positive correlation between the magnitude of preoperative total corneal astigmatism and the difference between postoperative total corneal astigmatism and anterior corneal astigmatism (R=0.378, P=0.001). A similar correlation between the magnitude of posterior corneal surface astigmatism and the difference between postoperative total corneal astigmatism and anterior corneal astigmatism (R=0.378, P=0.001) was also found. When analyzing the correlation between the magnitude of preoperative anterior astigmatism and the difference between postoperative total corneal astigmatism and anterior corneal astigmatism, we also verified a positive correlation (R=0.316, P=0.005), but of lower strength.

These findings suggest that the magnitude of preoperative astigmatism is related to the differences we observe when comparing anterior corneal astigmatism and total corneal astigmatism, suggesting that in individuals with higher astigmatism, estimating total corneal astigmatism while incorporating the posterior corneal surface aspects could be particularly relevant. Our results showed that among preoperative total corneal astigmatism, anterior corneal astigmatism and posterior corneal astigmatism; total and posterior corneal measurements showed the highest correlation. A previous work from Eom *et al.* [2014] studied 99 eyes verifying that the cylinder power difference between anterior corneal astigmatism and total corneal astigmatism was positively correlated with posterior corneal cylinder power (R=0.704 and P<0.001) (26). The evidence provided from our results was not as strong, which could be explained by the fact that our population consisted mainly in eyes with low to moderate astigmatism of ≤1.50 D. Future works with more patients and higher degrees of astigmatism are necessary to establish this relation and its characteristics.

We identify the following limitations of our study: population sizes being relatively small, especially when analyzing astigmatism changes in each subgroup and the difficulty of validating the accuracy of posterior corneal measurements, even though previous works with the Pentacam have shown good repeatability (19).

In conclusion, our study found that in our population, cataract surgery did not modify significantly the magnitude of corneal posterior astigmatism; and that there is a statistically significant difference between anterior corneal astigmatism and total corneal astigmatism, stressing the clinical relevance of incorporating posterior corneal surface measurements in this calculation. Higher preoperative magnitudes of total corneal astigmatism and posterior corneal astigmatism are positively correlated with the postoperative difference between anterior corneal astigmatism and total corneal astigmatism, suggesting that this evaluation could be especially relevant in patients with higher degrees of astigmatism.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments. Informed consent was obtained from all individual participants included

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