Original Article

Paired Opposite 4 mm Clear Corneal Incisions on Steep Meridian during Phacoemulsification

Nazanin Binayi Faal[1], Habib Ojaghi[2], Saeid Sadeghieh Ahari[3]

[1]School of Medicine, Ardabil University of Medical Sciences, Ardabil, Iran, [2]Department of Surgery, School of Medicine and Allied Medical Sciences, Imam Reza Hospital, Ardabil University of Medical Sciences, Ardabil, Iran, [3]Department of Community Medicine, School of Medicine and Allied Medical Sciences, Ardabil University of Medical Sciences, Ardabil, Iran

Abstract

Purpose: To evaluate the effect of opposite clear corneal incisions (OCCI) with 4 mm incisions on the steep meridian on postoperative astigmatism.

Methods: This study was performed on 64 eyes of 55 patients with keratometric astigmatism of ≥ 1 diopter (D) undergoing phacoemulsification. Patients were divided into two groups, with-the-rule (WTR) astigmatism and against-the-rule (ATR) astigmatism. Initial incisions in the WTR group were performed on the temporal side with 3.2 mm keratome and paired stab incisions were performed on the steep meridian. At the end of the surgery, stab incisions were enlarged to 4 mm. Follow-up visits were scheduled at 1, 3, 6, and 12 months postoperatively, which included refraction and keratometry.

Results: It was found that the mean preoperative keratometric astigmatism was 2.06 ± 0.86 D. The postoperative mean keratometric astigmatism was 1.3 ± 0.7 D after 1 month and 1.2 ± 0.7 D after 12 months. The mean astigmatism correction between the preoperative measure and that taken at 1 month was statistically significant ($P = 0.001$), but there was no significant change in the severity of astigmatism afterward. The mean surgically-induced astigmatism was found to be 1.99 ± 0.9 D. The 12-month changes of mean absolute astigmatism were: 1.06 ± 0.7 D in the WTR group, and 0.53 ± 0.7 D in the ATR group. The difference between the two groups was statistically significant ($P = 0.02$).

Conclusion: Based on our findings, we posit that paired OCCI on the steep axis, using 4 mm incisions is an effective technique to correct preoperative astigmatism.

Keywords: Astigmatism, Cataract, Opposite clear corneal incisions, Phacoemulsification

Address for correspondence: Habib Ojaghi, Department of Surgery, School of Medicine and Allied Medical Sciences, Imam Reza Hospital, Ardabil University of Medical Sciences, Ardabil, Iran.
E-mail: habibojaghi@yahoo.com
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Introduction

In recent years, the correction of astigmatism has become a goal during cataract surgery and has been modified using a variety of procedures.[1-5] These have included: changing the size and location of incisions, relaxing incisions in the cornea or limbus, clear corneal paired incisions at the steep meridian, as well as applying toric intraocular lenses, excimer lasers, and femtosecond laser astigmatic keratotomy.[1-5]

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Each of the mentioned procedures has their own disadvantages, such as the high cost of toric intraocular lenses, the probability of rotation of the toric lens after surgery, the absence of the excimer laser in many surgical centers, and the need for expensive diamond knives in relaxing incisions, as well as conflicted perspectives related to multiple nomogram usage.[6] The prevalence of keratometric astigmatism of 1–2.5 diopters (D) has been estimated to be 24%–36% after routine cataract surgery.

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The most common cause of wearing glasses after phacoemulsification is astigmatism.[2,7] Cataract surgery is a good opportunity to correct corneal astigmatism. For this purpose, there are many options available to surgeons that are performed without the use of additional tools, high cost, and additional surgical time. One of these methods is the paired clear corneal incision (CCI) at the steep corneal meridian, as performed in initial work by Lever and Dahan in 2000.[5,6,8-10] There have been various studies which have performed paired corneal incision with sizes <4 mm, and there are also suggestions for cataract surgery with 4 mm corneal incisions in different studies.[11] This present study was performed to evaluate the efficacy of 4 mm corneal incisions at the steep meridian during phacoemulsification. We believe that this procedure is the first in the world to reduce preoperative astigmatism, according to our knowledge.

Methods

This prospective quasi-experimental study for comparison of post and presurgical keratometric astigmatisms included 64 eyes of 55 cataract surgery candidates with corneal astigmatism ≥1 D. It took place between January 1, 2018, and December 30, 2018. The inclusion criteria were all cataract surgery candidates with astigmatism ≥1 D, without a history of previous keratorefractive surgery, previous trauma, corneal scar, ptosis, and irregular corneal astigmatism.

The written informed consent for prospective data analysis was obtained from patients during their recruiting process. The study and consent procedure were approved by the Ardabil University of Medical Sciences Ethics Committee (No: IR.ARUMS.REC.1396.165) with IRCT NO (20180406039208N1) and adhered to the tenets of the Declaration of Helsinki.

In most patients, corneal keratometry was performed with a Canon Full Auto Ref_Keratometer RK-F2 (Canon Inc., Shimomaruko 3-chome, Ohta-ku, Tokyo, Japan). Keratometry was performed with a Javal Keratometer (CSO) in cases where a Canon Keratometer was unavailable.

Due to the probability of cyclotorsion, the cornea was marked with Gentian Violet at 6 and 12 o'clock, before phacoemulsification cataract surgery. The steep meridian in the patient's lying supine was marked on the operating room bed by Mendez, and incisions were then made with a 3.2 mm keratotomy knife. According to the type of astigmatism, the patients were divided into against-the-rule (ATR), and with-the-rule (WTR). In the WTR group, the main incision of 3.2 mm was made perpendicular to the steep meridian for the entrance of the phaco handpiece, and stab incisions were made precisely on the steep meridian. At the end of the operation, the size of these incisions in the steep meridian was increased from both sides to exactly 4 mm by using a keratotomy knife and surgical caliper. In the ATR group, the primary temporal incision was 3.2 mm on the steep meridian, followed by two stab incisions (1.5 mm) perpendicular to the steep meridian. At the end of the operation, the size of the paired corneal incisions corresponding to the steep meridian was again increased to 4 mm and no suture was used at the end of surgery. Corneal stromal hydration was not performed for any incisions. All surgical procedures were performed by the same surgeon. Postoperatively, all patients were treated with betamethasone (one drop every 2 h for 1 week) tapered by 1.5 months after the second week. Patients also received chloramphenicol, and one drop was given every 6 h. All patients were examined the next day and at the following times points: 1 week, 1 month, 3 months, 6 months, and 12 months postsurgery.

All patients were divided into three groups according to the site of the steep meridian of cornea; (1) WTR in the range of 90 ± 30 meridian; (2) the ATR in the range of 180 ± 30 meridians; (3) oblique in the range of 31–59 and 121–149 degrees. Patients were divided into three groups based on the degree of astigmatism: (1) Mild: 1–1.49 D; (2) Moderate: 1.5–1.99 D <2; (3) Severe: More than 2 D. Astigmatic vectors were analyzed and reported according to Alpin's method.[12,13] Surgically-induced astigmatism (SIA) vector is the vector of the astigmatic change actually induced by the surgery. Target-induced astigmatism (TIA) is the vector of the astigmatic change intended to be induced by the surgery. The correction index (CI) is the ratio of SIA to TIA and is preferably a value of 1.0. CI >1.0 and CI <1.0 indicate an overcorrection and undercorrection, respectively. The difference vector (DV) is the magnitude and axis of astigmatic change that would enable the initial surgery to achieve its intended target. The DV is an absolute measure of success and is preferably zero. Index of success (IOS) is calculated by dividing the DV by TIA. The IOS is a relative measure of success and is preferably zero. A CI of 1.00 and an IOS of 0 indicate that the desired results have been achieved. The magnitude of error (ME) is the difference between the magnitude of SIA and TIA. The angle of error (AE) is the difference between the angles of the SIA and TIA. The flattening effect (FE) is the amount of astigmatism reduction achieved by the effective proportion of the SIA at the intended meridian (FE = SIA × COS 2 × AE). The flattening index (FI), which preferably equals 1, is obtained by dividing the FE by the TIA.

The average Keratometry Calculator v 1.01 software was used to convert the corneal power, as measured by the keratometer, to the severity of astigmatism (D), as well as average corneal strength on the steep axis.[14] In addition, the Astigmatic Vector Analyzer v. 2004 software was used to calculate vectors and indices of astigmatic changes such as TIA, SIA, DV, IOS, CI, ME, AE, FE, FI, Torque effect.[15]

Statistical analysis

Data were entered in SPSS software (SPSS 24: IBM Company, Chicago, Illinois, USA). Each eye ($n = 64$) was considered to be an analytical unit. The data were then plotted into charts using descriptive statistics. Statistical indices were analyzed using statistical tests including analysis of variance, paired and independent *t*-test, and correlation analysis of variables. $P < 0.05$ were considered statistically significant.

Results

The study was performed on 69 eyes from 60 patients. During 1 year of follow-up, 1 patient died, 3 patients did not return for follow-up, and 1 patient had edema and corneal irregularity that was excluded from the study. Therefore, the final analysis was performed on 64 eyes of 55 patients undergoing cataract surgery, with astigmatism ≥1 D. Nine patients with both eyes were enrolled into the study. Of the 55 patients studied, 17 (31%) were male and 38 (69%) were female (mean age 60.4 ± 16.1 years and age range of 22–88 years).

The left eyes (34 eyes; 53.1%), and the right eye (30 eyes; 46.9%) were found to be involved. The highest frequency of cataract type was posterior subscapular, with 53 eyes (82.8%). This was followed by nuclear sclerosis, with 42 eyes (65.6%), and cortical with 12 eyes (18.8%). There was the possibility of simultaneously mixed cataracts in each eye, so the groups overlapped. Eyes were divided into three groups according to the steep meridian: WTR was prevalent in the greatest frequency (38 eyes: 59.4%), followed by the ATR group (23 eyes: 35.9%) and oblique astigmatism group (3 eyes: 4.3%).

According to Table 1 and Figure 1, the highest severity of keratometric astigmatism was preoperative, which significantly decreased in the 1st month after surgery, from an average of 2.06 ± 0.8 diopters to 1.3 ± 0.7 diopters (P = 0.001). Subsequently, stability was observed in keratometric astigmatism after follow-ups at 3, 6, and 12 months.

The mean corneal power (mean K) was also increased from 44.3 ± 1.7 D preoperatively to 44.45 ± 1.68 D 12 months after surgery. Given that significant changes of more than 0.25 D in keratometry were clinically important to us in postoperative follow-up, this change was not considered significant [Table 1 and Figure 2].

It was found that the most changes or shifts of the preoperative steep meridian were in the 1st month after surgery and no significant changes were observed afterward [Figure 3]. The steep meridian had a considerable change until the 1st month after surgery and then stabilized.

Changes in the severity of keratometric astigmatism over time in the WTR and ATR types at 12 months postoperation were significant (P = 0.001). However, there were no significant changes observed in oblique astigmatism (P = 0.058). Astigmatism has been shown to be associated with a reduction of severity after surgery. This difference was noticeable between the WTR and ATR groups [Table 2].

Comparison of types of astigmatism showed only significant difference between WTR and ATR (P = 0.02) in the 12 months postoperatively. There was no significant difference between the other groups. According to the age distribution, there was no significant difference between the different age groups in reducing the severity of astigmatism at 12 months, in comparison with the preoperative visit (P = 0.5). The effect of

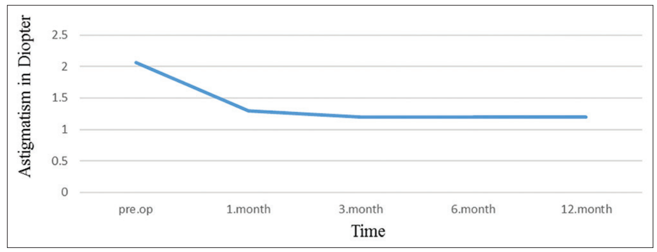

Figure 1: Changes in severity of preoperative keratometric astigmatism over time

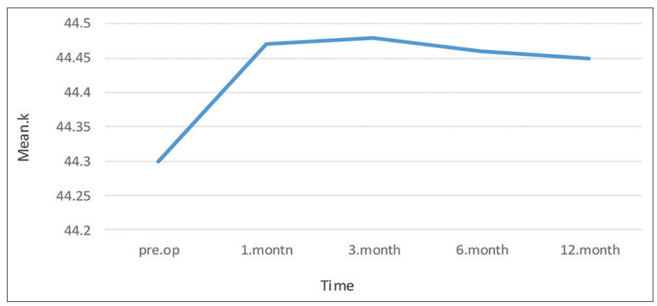

Figure 2: Changes in mean corneal power (keratometry) in diopters over time

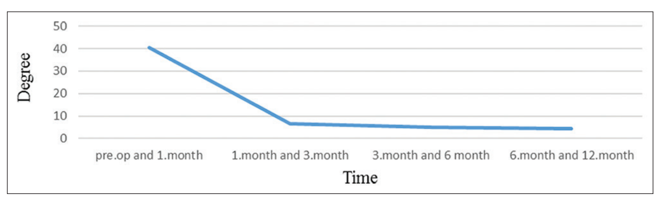

Figure 3: Steep corneal axis changes compared to previous visit

Table 1: Mean keratometric astigmatism and mean keratometry changes according to time of visits

Parameters	Time of visit (months)				
	Preoperation	1st	3th	6th	12th
Keratometric					
Mean±SD	2.06±0.8	1.3±0.7	1.2±0.6	1.2±0.6	1.2±0.7
Range	1-5.13	0.1-3	0.12-3.13	0.25-3.12	0.2-2.6
Mean K (Diopter)					
Mean±SD	44.3±1.7	44.47±1.7	44.48±1.68	44.46±1.7	44.45±1.68
Range	40.25-48.31	40.56-48.00	40.50-48.44	40.56-48.31	40.36-48.37

K: Keratometry, SD: Standard deviation

opposite CCI (OCCI) according to preoperative astigmatism severity is shown in Table 3. There was a significant difference between the three groups (*P* = 0.001).

Table 4 also compares the groups with different levels of preoperative astigmatism for 12-month changes in astigmatism. These changes were not significant in comparison of the mild group with moderate groups (*P* = 0.5).

However, there was a significant difference found between the severe group against moderate (*P* = 0.001) and mild (*P* = 0.001) groups. In other words, surgical intervention had a greater effect on more severe preoperative astigmatism, as compared to its milder cases.

The findings of the vector analysis are shown in Table 5, and Figures 4-7. In this study, the target value for postoperative astigmatism was zero and the CI value was close to 1 (1.04 ± 0.5 D), indicating success in surgery. The value of IOS (DV/TIA ratio) is zero if surgery is successful. In this study, the IOS was 0.6 ± 0.29 D, indicating the relative success of the surgery. A more thorough analysis of some of the indices is presented in Table 6.

Based on the scattergram [Figure 8], the correlation coefficient of TIA and SIA was determined to be 0.39, which was significant (*P* = 0.001). In fact, although the TIA and SIA have significant correlations, this correlation was not found to be complete, and other causes influenced the CI value in this study. The degree of AE indicates the shift of the steep axis during the postoperative correction. The positive number represents the counter-clockwise shift, and the negative number represents the clockwise shift. As shown in Table 5, the mean AE was calculated to be −0.58 ± 13.1, indicating an overall movement in the clockwise direction. Furthermore, the number of negative cases was determined to be 29 eyes (45.3%) with a mean of -12.8 ± 7.3 and the number of positive cases (counter-clockwise) was also seen in 35 eyes (45.3%). The mean score was 9.57 ± 6.5 [Table 6].

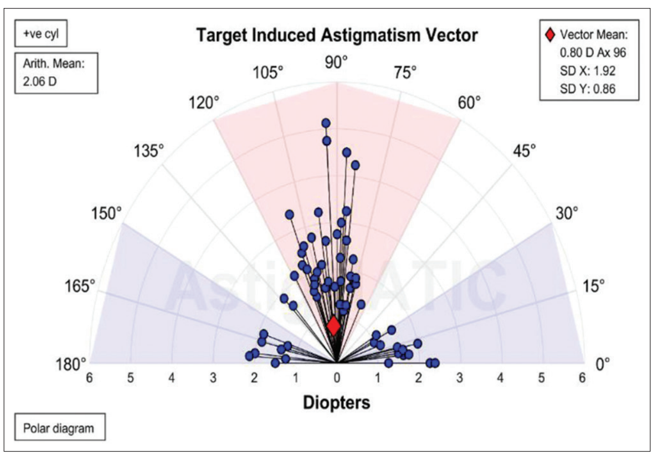

Figure 4: Target induced astigmatism vectors of patients

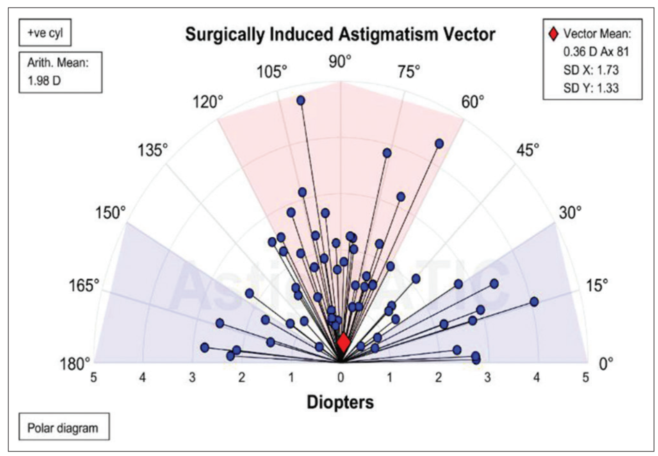

Figure 5: Surgically induced astigmatism vectors of patients

Table 2: Opposite clear corneal incision result according to type of astigmatism

Astigmatism type	Time	Mean astigmatism (12 months vs. preoperative) mean±SD (Diopter)	Mean difference (Diopter)	*P*
WTR	12 months	1.29±0.7	−1.06	0.001
	Preoperation	2.35±0.9		
ATR	12 months	1.12±0.6	−0.53	0.001
	Preoperation	1.64±0.36		
Oblique	12 months	0.68±0.3	−0.87	0.058
	Preoperation	1.54±0.4		

WTR: With-the-rule, ATR: Against-the-rule, SD: Standard deviation

Table 3: Opposite clear corneal incision effect by astigmatism severity

Preoperation astigmatism severity (Diopter)	*n* (%)	Mean (12 months vs. preoperation) astigmatism changes (Diopter) (mean±SD)	*P*
Mild <1.5	12 (18.8)	−0.3±0.1	0.001
Moderate 1.5≤ Ast <2	26 (40.6)	−0.58±0.1	
Severe ≥2	26 (40.6)	−1.38±0.16	

SD: Standard deviation

No significant difference was found in the amount of SIA between the three types of astigmatism. This means that the type of astigmatism is not effective in SIA. SIA values in the three types of WTR, ATR, and oblique were found to be: 1.96 ± 1, 2.13 ± 0.9, and 1.4 ± 0.9, respectively. As indicated in Table 7, a significant difference was observed between the types of astigmatism in terms of the amount of correction (overcorrection or undercorrection) after surgery (P = 0.003), where 58.6% of overcorrections belong to people with ATR astigmatism and 77.1% of undercorrections belong to subjects with WTR astigmatism. Our results demonstrated a significant difference between the ATR and WTR groups in terms of correction rate (P = 0.001). However, no significant difference was found between the other groups.

Table 4: Paired comparison of different severities of astigmatism

Preoperation astigmatism severity (Diopter)	Mean 12 months astigmatism changes (Diopter) (mean±SD)	*P*
Mild versus	−0.3±0.1	0.50
Moderate	−0.58±0.1	
Moderate versus	−0.58±0.1	0.001
Severe	−1.38±0.16	
Mild versus	−0.3±0.1	0.001
Severe	−1.38±0.16	

SD: Standard deviation

Discussion

In the present study, the mean preoperative astigmatism was determined to be 2.06 ± 0.8 D, while the mean 1, 3, 6, and 12 months follow-up were 1.3 ± 0.7 and 1.2 ± 0.6, 1.2 ± 0.6, and 1.2 ± 0.7 D, respectively. The decrease in astigmatism was 0.76 D during the 1st month after surgery, while it was 0.85 D at 12 months postoperatively. Patients were stable for changes in the severity of stigmatism at the end of month 1.

Various researchers have found different astigmatisms when comparing preoperative and postoperative measures. In one study, Lever and Dahan performed 2.8–3.5 mm paired OCCIs on 33 eyes. The authors found that preoperative and postoperative (12 months) astigmatism were 2.81 ± 0.74 and 0.75 ± 0.6 D, respectively, and the 12-month average decline was determined as 2.25 D.[5]

In 2004, Tadros evaluated OCCIs in phacoemulsification on decreasing preoperative keratometric astigmatism.[16] The study found that 103 patients with a 3.5 mm incision had mean preoperative astigmatism of 1.48 ± 0.96 D, while astigmatism of 0.5 ± 0.73 D was found at 6–8 weeks after surgery.[16]

In a study by Simon and Desatnik, 34 patients underwent clear cornea phacoemulsification cataract extraction with 3.2-mm OCCIs.[17] Preoperative astigmatism was determined to be 2.6 ± 1.2 D, as compared to postoperative astigmatism (1.4 ± 0.9) with a mean correction of 1.3 ± 0.9 D.[17]

A randomized prospective clinical study evaluated the astigmatic correcting effect of OCCIs on 40 eyes with 3.2 mm

Table 5: Vector analysis

Parameters	SIA (Diopter)	TIA (Diopter)	DV	AE (°)	ME	CI	IOS	FE	FI	Torque
Mean±SD	1.99±0.9	2.1±0.9	1.19±0.65	−0.58±13.1	−0.59±1	1.04±0.50	0.6±0.29	1.8±0.9	0.93±0.46	−0.05±0.9
Range	0.25-4.72	1.00-5.13	0.2-3.6	-25.01-24.9	-2.62-1.96	0.2-2.1	0.16-1.46	0.25-4.16	0.2-1.2	-3.26-1.57

SIA: Surgically induced astigmatism, TIA: Target induced astigmatism, DV: Difference vector, AE: Angle of error, ME: Magnitude of error, CI: Correction index, IOS: Index of success, FE: Flattening effect, FI: Flattening index, SD: Standard deviation

Table 6: Vector analysis in terms of correction rate

Parameters	AE		ME		CI		Torque (Diopter)	
	Clock wise	Counter-clockwise	Over correction	Under correction	Over correction	Under correction	45 clock wise	Counter-clockwise
n (%)	29 (45.3)	35 (54.7)	29 (45.3)	35 (54.7)	29 (45.3)	35 (54.7)	29 (45.3)	35 (54.7)
Mean±SD	−12.8±7.3	9.57±6.50	0.8±0.50	−0.77±0.6	1.49±0.3	0.66±0.2	−0.86±0.74	0.61±0.39

AE: Angle of error, ME: Magnitude of error, CI: Correction index, SD: Standard deviation

Table 7: Paired comparison of correction rate by astigmatism type

Astigmatism type	Overcorrection, *n* (%)	Undercorrection, *n* (%)	*P*	
WTR	11 (37.9)	27 (77.1)	0.001	0.003
ATR	17 (58.6)	6 (17.1)		
Oblique	1 (3.4)	2 (5.8)	0.8	
WTR	11 (37.9)	27 (77.1)		
Oblique	1 (3.4)	2 (5.8)	0.15	
ATR	17 (58.6)	6 (17.1)		

WTR: With-the-rule, ATR: Against-the-rule, *n*: Number

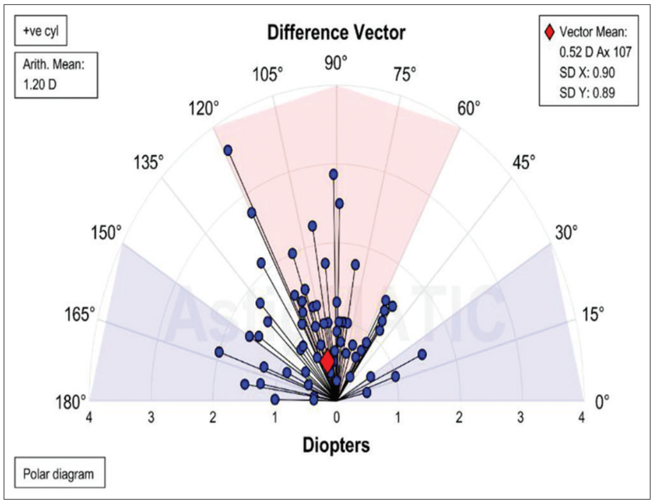

Figure 6: Difference vectors of patients

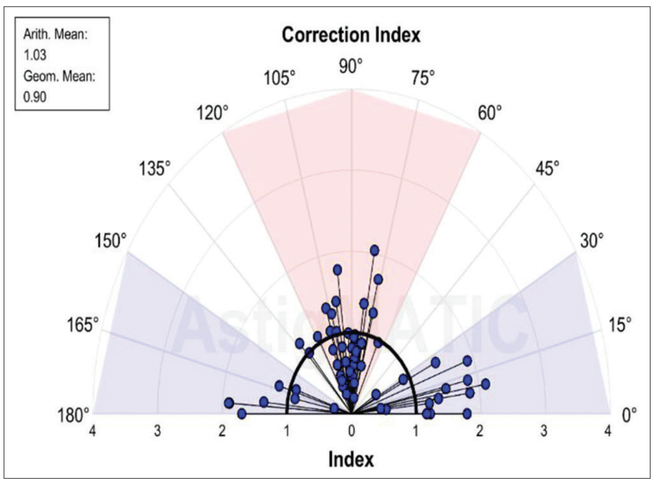

Figure 7: Correction index of patients

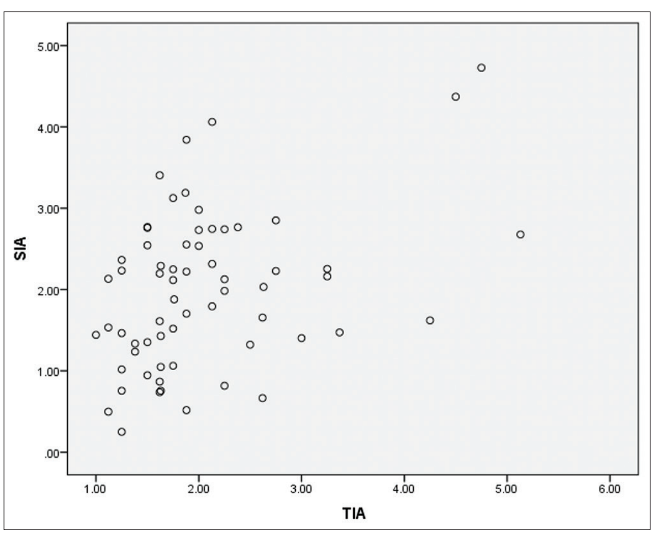

Figure 8: Scatter gram of target induced astigmatism and surgically induced astigmatism

incisions.[18] The average preoperative, postoperative (1 month and 3 months) keratometric astigmatism were found to be: 2.51 ± 0.92 D, 1.00 ± 0.6 D and 0.91 ± 0.54 D. The average of 3-month changes was recorded as 1.60 ± 0.45 D. Patients were stabilized for changes in the severity of astigmatism at week 4 postoperatively,[18] which is consistent with the present study.

Alam reported postoperative changes in astigmatism as 0.58 D at the end of 2 months using a 3.2 mm incision.[19] In another study, the OCCI group with a 3-mm incision had astigmatism changes from 2.31 ± 1.6 to 1.11 ± 1.1 D during the 6-month postoperative period. The correction amount was 1.2 ± 0.9 D.[7] Nemeth in 2014 reported a change in the severity of astigmatism from 1.60 ± 0.34 to 0.8 ± 0.68 D on 81 patients with a 3 mm incision within 9 weeks.[20] Žemaitienė *et al*. assessed phacoemulsification patients undergoing 4 mm CCI group and 3 mm incision (OCCI groups), where the severity of postoperative astigmatism was evaluated up to 6 months. In the OCCI group, preoperative and postoperative astigmatism (6th month) were 2.23 ± 0.21 and 1.56 ± 0.18 D, respectively.[11] The results of this study were closer to the severity of astigmatism in our study. Similar to our study, in all these studies, preoperative astigmatism decreased significantly by paired OCCI. Therefore, our work is in concordance with the findings of these studies showing how paired OCCI can decrease astigmatism following surgery.

In the present study, mean preoperative corneal power was 44.3 ± 1.7 D, while postoperative values for the first, third, 6th, and 12th months were recorded as 44.47 ± 1.7, 44.48 ± 1.68, 44.46 ± 1.7, and 44.45 ± 1.68 D, respectively. Patients had no significant changes in mean corneal power at 1 month postoperatively. This data is consistent with another study,[18] where the authors indicated that mean preoperative corneal power and postoperative power for 4th week (1 month) and 12th week (3 months) were 44.46 ± 1.94, 44.26 ± 1.92, and 44.23 ± 1.96 D, respectively. Patients were stabilized for changes in corneal power at 1-month postoperation.[18]

Another study has assessed the effects of OCCI on mean keratometry in 84 patients undergoing phacoemulsification by 6 months follow-up.[8] Patients were divided into three groups: Group A (WTR astigmatism), Group B (ATR astigmatism), and Group C (ATR astigmatism). The keratome length applied for Groups A and B was reported to be 3.2 mm, and for other Group C was 3.5 mm. They were evaluated for mean corneal power preoperatively and at 1 and 6 months postoperatively. In Group A, the mean preoperative corneal power was determined as 44 D. Postoperative values for the first and 6th months were 44.2 and 44.4 D, respectively. Preoperative and postoperative corneal powers for Group B were: 44.6, 44.2, and 44.4 D and for Group C was 44.2, 44, and 44 D, respectively. No significant changes in corneal power were observed in any of the groups over the 6-month period.[8] In the current study, the changes in the 1st month were not significant because the stability limit was set at 0.25 D.

In the present study, the changes and shifts of the steep axis before surgery and 1 month after surgery were 40.61 ± 26.1 degrees, which was statistically significant. There was no significant change in the steep axis in the following months, and the steep axis stabilized after 1st month.

Simon and Desatnik performed phacoemulsification cataract extraction with 3.2-mm OCCIs, where the steep axis shifted from 88 ± 51 D, preoperatively to 68 ± 58 degrees by 8 months postoperatively. No significant postoperative changes in steep-axis shifts were observed,[17] which is inconsistent with the results of the present study. Due to the larger incision length of the present study (4 mm) compared to the above-mentioned study, it is possible to make more axial shift by larger incisions.

In the present study, patients were also divided into three groups according to the severity of preoperative astigmatism. Astigmatism changes at 12 months in the mild group were 0.3 ± 0.1 D, followed by the moderate (0.58 ± 0.1 D) and severe (1.38 ± 0.16) groups. A significant difference was found between different groups in the changes of the severity of astigmatism (P = 0.001), demonstrating that 4 mm paired OCCIs had a more greater effect on the reduction of preoperative astigmatism at a higher severity of astigmatism. In another study where the mean preoperative astigmatism in all groups was <2 D, the effect of a 3.2 mm CCI was observed in moderate-to-severe astigmatism.[1] This was not in concordance with our present study. This may suggest that if there are larger incisions, then there may be a higher degree of astigmatism correction. However, further studies with a greater sample size are required to evaluate the effects of paired corneal incisions at different levels of preoperative astigmatism severity.

In the present study, the prevalence of WTR group was 59.5%, followed by the ATR group (35.9%) and oblique group (4.7%). The decrease in the severity of astigmatism over time, during the 12-month postoperative period, was recorded as 1.06 D in the WTR group, followed by the ATR group (0.53 D) and the oblique group (0.87 D). In addition, a significant difference was found between the WTR and ATR groups in reducing the severity of astigmatism (P = 0.02). An investigation by Bhalla *et al*.[21] divided patients into three groups: No preoperative astigmatism, a WTR group, and an ATR group. In each patient group, there were 15 eyes. Phacoemulsification was performed via 2.8 mm CCI. The mean postoperative astigmatism decreased from 1.16 ± 0.32 D in the WTR group, preoperatively, to 0.46 ± 0.28 D at 3 months, postoperatively. Furthermore, preoperative astigmatism decreased from -1.25 ± 0.32 D in the ATR group, to -0.38 ± 0.31 D at 3 months, postoperatively. In the study, astigmatism reduction was found to be statistically significant in both WTR and ATR groups (P < 0.001). However, there was no significant difference in preoperative astigmatism reduction between the two groups,[21] which is not consistent with the present study conducted by our clinicians.

In a randomized clinical trial by Bazzazi *et al*., the mean keratometric astigmatism of 120 eyes was recorded as 1.82 ± 0.86 D in a WTR group and 1.74 ± 0.86 D in an ATR group preoperatively, while postoperative values decreased to 1.31 ± 0.59 and 1.19 ± 0.64, respectively. Comparison of pre and postoperative astigmatism changes in the WTR and ATR groups was statistically significant (P < 0.001), but no significant difference was found between the two groups mentioned in,[1] which was also not in concordance with the work we performed.

In the present study, mean preoperative astigmatism was 2.06 ± 0.8 D and 12 months postoperative SIA was 1.99 ± 0.9 D. One study by Tadros indicated that the mean severity of preoperative astigmatism was 1.48 ± 0.96 D with a 3.5 mm incision, and the mean SIA at week 8 postoperatively was 1.57 D.[16] Sundeshan reported that the mean preoperative astigmatism was 2.51 ± 0.92 D with a 3.2 mm OCCI incision, and the severity of SIA was recorded 1.66 ± 0.05 D at week 12, postoperatively.[18] Singh reported a preoperative astigmatism severity of 0.77 ± 0.5 D with a 2.8 mm OCCI incision while mean SIA at week 4 and 6 postoperatively were 1.02 ± 0.68 and 0.66 ± 0.67%, respectively.[22] Koyun, *et al*. demonstrated that the mean preoperative astigmatism in the OCCI group was 2.31 ± 1.6 mm, and the SIA was 1.78 ± 0.91 at 6 months, postoperatively.[7]

Our study indicated that the SIA values in the WTR and ATR groups were 1.96 ± 1 D and 2.13 ± 0.9 D, respectively; no significant difference in the severity of SIA was found between the types of astigmatism (P = 0.48). In a study by Bazzazi *et al*., the SIA in the WTR and ATR groups was found to be 0.79 ± 0.50 D and 0.68 ± 0.55 D, respectively. The severity of SIA did not show a significant difference in all types of astigmatism,[1] which is consistent with the present study.

Vector analysis was performed using the Alpin method in our work. The mean SIA vector was 1.99 ± 0.9 D, followed by the mean TIA vector (2.1 ± 0.9 D), the mean DV vector (1.19 ± 0.65 D), and AE (0.58 ± 13.1 degrees), ME (0.59 ± 1 D), IOS (0.6 ± 0.29), FE (1.8 ± 0.9), FI (0.93 ± 0.46), and torque effect (-0.05 ± 0.9).

Research by Razmjoo[23] also examined the results of vector analysis by the Alpin method. Their study may be compared with the findings of our work. The authors found the following: SIA (1.59 ± 0.24 D), CI (0.63 ± 0.005), IOS (0.56 ± 0.001), ME (1.11 ± 0.171), AE (4.30 ± 0.098 degrees) and torque effect (0.02 ± 0.042 D). Their and our study IOS values were close to zero, which are close to an ideal situation clinically. In the present study, AE examination showed that 54.7% of eyes (mean 9.57 ± 6.5 degrees) had counter-clockwise rotation while clockwise rotation was attributed to 45.3% of eyes (mean-12.8 ± 7.3 degrees). In the present study, the mean AE in all patients was negative (clockwise), while its value was found to be positive (clockwise) in the Razmjoo study.[23] The CI value of 1.04 ± 0.5 was the mean correction in the present study, which was close to the ideal value of 1. It can be concluded that although the values of TIA and SIA were linearly correlated, this relationship was not complete according to the distribution of SIA and TIA indices in scatterplot.[7] Furthermore, the correlation value was 0.39 (P = 0.001). These indicate the effect of other factors on the CI index, such as overcorrection and undercorrection, the creation of new axis or post-surgical axis rotation.

In the present study, 45.3% of the cases showed overcorrection (mean: 1.49 ± 0.3) while 54.7% of the cases revealed undercorrection (mean: 0.66±0.2). We found that 77.1% of undercorrection and 37.9% of overcorrection belonged to people with WTR astigmatism, whereas 58.5% of overcorrection and 17.1% of undercorrection were found to belong to subjects with ATR astigmatism. Therefore, the number of cases of correction type showed a statistically significant difference in the two WTR and ATR groups ($P = 0.001$). According to what was mentioned earlier in this study, the 12-month change in the average severity of astigmatism in the ATR and WTR groups was determined as 0.53 and 1.06 D, respectively. The 12-month changes in the severity of astigmatism in the ATR type were lower than the WTR. However, it should be noted that the presence of the main keratotomy incision on the temporal side of the cornea reduces the effect of paired corneal incision at the vertical meridian of the cornea in the WTR group. In the ATR group, the main incision is one of the paired corneal incisions and thus did not have a decreasing effect on the paired incisions. Taking this into account, the overcorrection in the ATR group and the undercorrection in the WTR group can be justified. Confirmation of this is seen in the different SIAs of all types of astigmatism, where SIA values for WTR and ATR groups were recorded as 1.96 ± 1 and 2.13 ± 0.9 D, respectively. In addition, even SIA values were found to be nonsignificantly higher in the ATR group than in the WTR group.

One of the limitations of the present study was the smaller number of eyes with oblique and ATR astigmatisms, which was predictable due to the higher prevalence of the WTR astigmatisms in the community. Other limitations included: The small number of ocular samples examined and the long postoperative follow-up period, which resulted in follow-up loss in some patients.

In conclusion, phacoemulsification surgery with 4 mm paired OCCI is an effective method for correction of different types of astigmatism, especially in moderate and severe types but due to the lack of superiority of 4 mm corneal incisions to smaller incisions, the abovementioned incisions are not recommended. Given to coincidence of phaco incision at the steep meridian, incisions <4 mm are recommended for preventing overcorrection in ATR astigmatisms.

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Conflicts of interest
There are no conflicts of interest.

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