Original Article

DOI: 10.17354/ijss/2016/152

Targeting Emmetropia in a Pseudophakic Eye: A Prospective Study

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Abstract

Introduction: There are numerous techniques for dealing with astigmatism both during and after cataract surgery. Good uncorrected post-operative distance visual acuity can be obtained for a high percentage of cataract patients with pre-existing corneal astigmatism.

Purpose: To achieve emmetropia in patients undergoing cataract surgery by eliminating corneal astigmatism.

Materials and Methods: A total of 180 patients presenting with cataract underwent phacoemulsification surgery with intraocular lens (IOL) implantation, with procedures like clear corneal incision (neutral astigmatism), incision on steep axis (≤0.75 D), limbal relaxing incision (LRI) (0.75 –≤1.50 D), opposite clear corneal incision (OCCI) (1.50 –≤2.50 D), foldable toric posterior chamber IOL (PCIOL), and astigmatic keratotomy (AK) (≥2.50 D) in their eye, targeting emmetropia.

Results: A total of 30 eyes underwent phacoemulsification cataract surgery with clear corneal temporal incision achieved mean residual astigmatism of 0.24 D and standard deviation (SD) of 0.22. About 30 eyes with an incision on steep axis had mean residual astigmatism of 0.18 D and SD was 0.21. Around 30 eyes with LRI procedure with cataract surgery, mean residual astigmatism was 0.18 D and SD achieved was 0.21 with $P < 0.05$. 30 eyes with OCCI and phacoemulsification with clear corneal temporal incision achieved mean residual astigmatism of 0.37 D and SD of 0.27 with $P < 0.05$. 30 eyes which underwent foldable toric PCIOL procedure had mean residual astigmatism of 0.71 D and SD was 0.12 with $P < 0.05$. 30 eyes which were subjected to AK procedure had mean residual astigmatism of 0.41 D and SD of 0.38 with $P = 0.02$.

Conclusions: If right modality to tackle pre-operative astigmatism along with cataract is considered, the patient can be given 20/20 vision and can enjoy life with no dependence on spectacles and also patient may not require another refractive surgery to tackle the residual astigmatism.

Key words: Clear corneal incision, Foldable toric posterior chamber intraocular lens and astigmatic keratotomy, Incision on steep axis, Limbal relaxing incision, Opposite clear corneal incision, Phacoemulsification

INTRODUCTION

Naturally occurring (idiopathic) astigmatism is frequent with up to 95% of eyes having detectable astigmatism. It is estimated that approximately 70% of the general cataract population has at least 1.00 D of astigmatism, and approximately 33% of patients undergoing cataract surgery are eligible for the treatment of pre-existing astigmatism.[1,2]

Access this article online

www.ijss-sn.com

Month of Submission : 01-2016
Month of Peer Review : 02-2016
Month of Acceptance : 02-2016
Month of Publishing : 03-2016

Today, cataract surgery is regarded as a refractive surgery, aiming pseudophakic emmetropia, which makes eliminating corneal astigmatism critical.[3-5] Ferrer-Blasco *et al.*, studied the prevalence of corneal astigmatism before cataract surgery and found that; in 13.2% of eyes no corneal astigmatism was present; in 64.4%, corneal astigmatism was between 0.25 and 1.25 diopters (D) and in 22.2%, it was 1.50 D or higher.[6]

When planning a surgery, both the spherical and the astigmatic components should be taken into account to

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achieve post-operative outcomes as close to emmetropia as possible. Due to new developments in phaco tips, changes in operation techniques and the use of small incisions in cataract surgery which reduce the operation-induced astigmatism or make an inconsiderable change in the existing corneal astigmatism, the general aim of cataract surgery has gone from simple cataract extraction to ensuring the best visual acuity and quality without spectacle dependence.

The most important and critical step in treating the astigmatism is to find out the exact source, magnitude and axis of astigmatism and making the decision about which technique is appropriate for that patient. The cylindrical component is evaluated by automated and/or manifest refraction, placido ring reflections, keratometry and/or corneal topography primarily, but other factors need to be taken into account, such as age of the patient and the corneal characteristics of both eyes. To quantify the discrepancy between corneal and refractive astigmatism measurements, the corneal astigmatism value measured by topography or keratometry is subtracted from the refractive cylinder measured by wave front or manifest refraction and the vectorial difference is known as the ocular residual astigmatism, which is expressed in diopters.[7-9] Corneal topography provides a qualitative and quantitative image map based on an evaluation of the corneal curvature, also measure the power and astigmatism of the posterior corneal surface, which may improve the correlation.

With the refractive astigmatism,[10,11] Lucciola reported the first cases of non-penetrating corneal incisions, in 1886, where he also attempted to reduce astigmatism by flattening the steep corneal meridian in ten patients.[12]

Lans first appreciated that the flattening that occurs in a corneal meridian after placing a transverse incision was associated with steepening in the opposite meridian. He also demonstrated that the deeper and the longer incisions had more effect.[13]

In the 1940s, Sato began his work on radial and astigmatic keratotomy (AK).[14]

Nordan proposed a relatively simple method of straight transverse keratotomy, with target corrections in the range on 1-4 diopters.[15]

Consequently, Troutman and Swinger also discussed the benefits of corneal relaxing incisions to decrease residual astigmatism.[16]

Thornton's technique involved making paired arcuate incisions placed at the 7.0 mm and 8.0 mm optical zones, following a curve on the cornea, while Chavez *et al.*, recommended optical zone sizes as small as 5.0 mm.[17,18]

Nichamin developed an extensive nomogram for AK at the time of cataract surgery; "Intralimbal relaxing incision nomogram for modern phaco surgery," which has age adjustments for correction of against-the-rule astigmatism and with-the-rule astigmatism. It utilizes an empiric blade depth setting of 600 μm.[19-22]

Corneal astigmatism occurs due to unequal curvature along the two principal meridians of the anterior cornea and internal astigmatism due to factors such as the toricity of the posterior surface of the cornea, unequal curvatures of the front and back surfaces of the crystalline lens, or tilting of the crystalline lens with respect to the optic axis of the cornea. The aim of this study was to achieve neutral astigmatism in a pseudophakic eye and optimizing them for a different degree of astigmatism and to study the effect of different modalities used for correcting astigmatism in our study and rating them in their order of effectiveness.

MATERIALS AND METHODS

This was a general free hospital-based prospective study (Table 1). About 180 patients were included in this study. All patients visiting the outpatients' clinic and indoor patients diagnosed with cataract during the course of investigations were recruited after a due informed written consent in this study (Table 2). Pre-determined inclusion and exclusion criteria (as described below) were applied to all patients before a patient was accepted into the study to get 180 completed patients after an attrition rate of 10%. The study was started from May 2012 and was completed by May 2014. Recruitment phase was 2 year's follow-up phase 6 weeks post-operative for every patient (Figure 1).

Pre-operative cataract evaluation included: Cycloplegic refraction to rule out lenticular and corneal astigmatism (Figure 2). Corneal astigmatism by manual keratometry and corneal topography, the latter also ruled out conditions such as keratoconus and peripheral corneal degenerations. Pachymetry was done preoperatively. In the case of limbal relaxing incision (LRI) just inside the limbus, and at 7 mm optic zone for AK. A scan was done by SRKT formula for intraocular lens (IOL) power. IOP was measured in all cases by applanation tonometer. Slit lamp examination for cataract grading and fundoscopy to r/o retinal pathology. Written informed (W/I) consent of the patient taken before recruitment into the study.

Inclusion Criteria

1. All patients with established cataract on V/A of <6/18 and S/L changes

Table 1: Gender distribution

Type of incision	Male Count (%)	Female Count (%)
Clear corneal temporal incision with neutral axis	15 (50)	15 (50)
Incision on steep axis	11 (36.67)	19 (63.33)
Temporal incision with LRI	9 (30)	21 (70)
Incision on steep axis with OCCI	12 (40)	18 (60)
Clear corneal temporal with toric lens	13 (43.33)	17 (56.67)
Incision on steep with AK	10 (33.33)	20 (66.67)

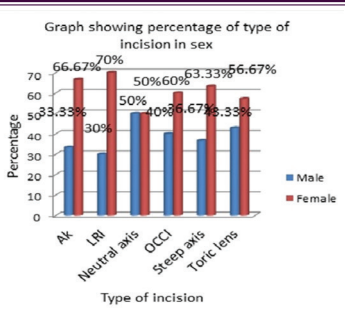
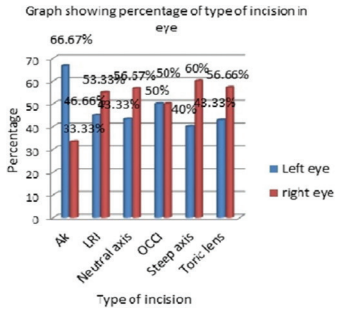


Table 2: Type of incision with respect to eye

Type of incision	Left eye Count (%)	Right eye Count (%)
Clear corneal temporal incision with neutral axis	13 (43.33)	17 (56.67)
Incision on steep axis	12 (40)	18 (60)
Temporal incision with LRI	14 (46.66)	16 (53.33)
Incision on steep axis with OCCI	15 (50)	15 (50)
Clear corneal temporal with toric lens	13(43.33)	17 (56.66)
Incision on steep with AK	20 (66.67)	10 (33.33)



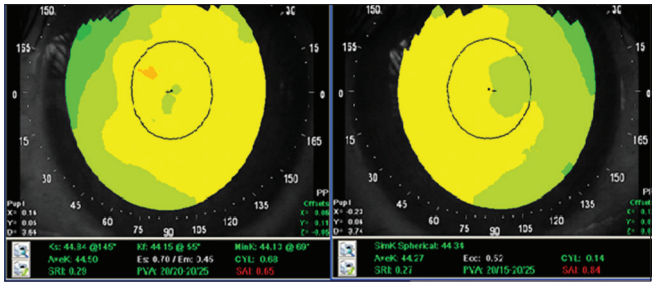


Figure 1: Clear corneal incision on the steep axis pre-operative and post-operative topography

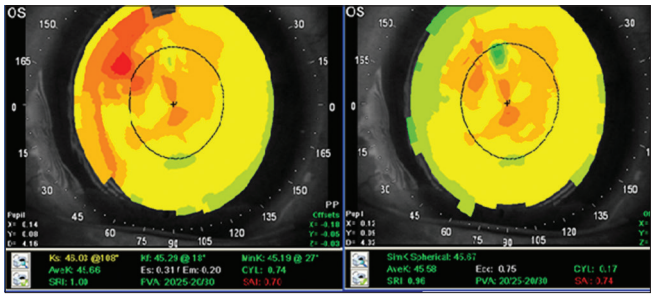


Figure 2: Clear corneal incision on the steep axis (superior incision). This is reflected in the incision on the steep axis (superior incision) where approx 0.6 D is getting corrected to give an astigmatic neutral incision

2. Age >18 years were chosen as FDA guidelines for corneal refractive surgery comments an age of at least 18 years
3. Sex - No criteria
4. Pre-operative astigmatism of nil to ≤6 diopters
5. Patent sac
6. No dry eye which could hamper wound healing and no retinal disease hampering V/A improvement
7. IOP: 14-19 mm Hg with C/D ratio <0.5
8. Grade of cataract: <grade 3
9. Systemic diseases controlled.

Exclusion Criteria

1. Non-complaint patient
2. Systemic diseases such as hypertension, diabetes mellitus, collagen vascular disease
3. Cataract like Grade 4 or 5 brown cataract (high phaco power needed may cause wound burn), subluxated cataract, pseudoexfoliated cataract, congenital cataract
4. Cornea: Keratoconus and central corneal thickness of <500 μ with a corresponding weak peripheral corneal thickness.

Methodology

Incision chart is stuck on the OT Wall to guide the operating surgeon. It has the eye marked with the steep meridian, along with the corneal topography photograph. W/I consent is taken from the patient before the initiation of surgery, peribulbar anesthesia given (however topical anesthesia was preferred before LRI and AK procedure), parts painted and draped, eye exposed with wire eye speculum (Figure 6). The incision was taken according to the keratometry and corneal topographic values of that particular eye (Figures 7,8).

a. Clear corneal temporal incision was used in cases with neutral astigmatism. A 2.8 mm keratometer was used and a triplanar clear corneal entry is made.
b. Incision on steep axis was used in cases with astigmatism of <0.75 D (Figure 9). A 2.8 mm keratome was used and a triplanar entry is made on the steep axis, and the surgery is performed from that incision (Figure 10).
c. LRI was used in cases with astigmatism of 0.75 D to 1.5 D according to keratometric, corneal topographic, and pachymertic values. LRI was made according to the Gills and Nichamin nomogram depending on the degree of astigmatism. Axis marking was done preoperatively on the slit lamp. The proper incision depth for LRIs was approximately 90% of the thinnest corneal depth around the limbus (Figure 3).[23] The cutting depth of the empiric blade was normally set to 550-600 μm (Figure 11). LRI was done before phacoemulsification procedure on topical anesthesia. The Clear corneal incision was made and a triplanar entry with a 2.8 mm keratome is done. Whole of the surgery was done from the temporal incision.

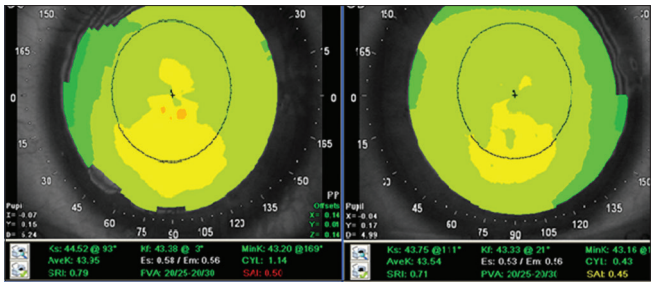


Figure 3: Temporal 3 mm clear corneal incision with limbal relaxing incision at 6 o'clock position. Correction achieved is approx 0.75 D (A11)

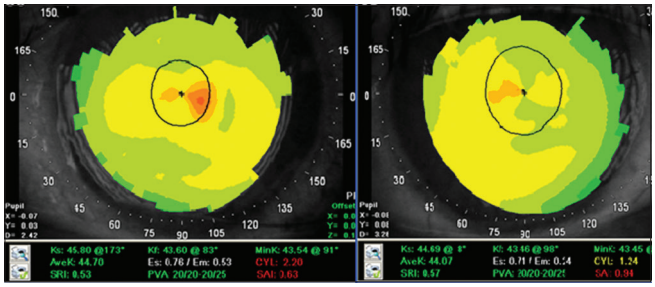


Figure 4: Astigmatism was >2 but <2.4 so a clear corneal temporal incision done and diagonally opposite opposite clear corneal incision done at the end of the surgery. The correction achieved was 0.96

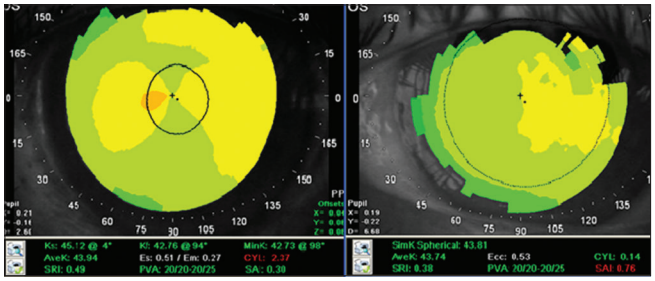


Figure 5: Temporal clear corneal incision with an AK in the superior and inferior quadrant 7 mm from the optical center, Arcuate in nature and 1 clock h in dimension. Correction achieved was approx 2.2 D

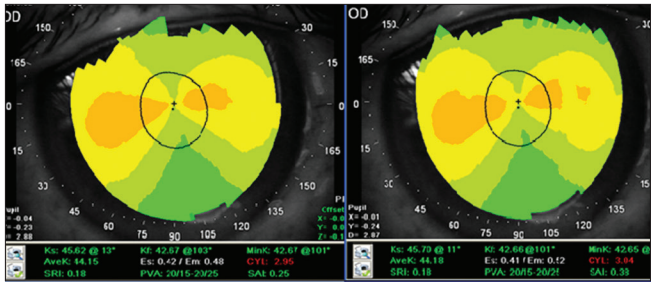


Figure 6: Pre-operative and post-operative cotopography remains almost same yet patient is 20/20 as astigmatism is internally compensated by the toric IOL

d. Opposite clear corneal incision (OCCI) was used in cases with astigmatism of 1.5 D to 2.5 D according to corneal topographic, keratometric and pachymetric values (Table 5). Incision was made on the steep axis and triplanar entry with 2.8 mm keratome was made and surgery was performed from the same entry. Before insertion of the lens a similar OCCI was made (i.e., opposite to the main incision) and entry in the cornea was done with a 2.8 mm keratome. No instrumentation or surgical procedure was done from this entry.

Figure 7: Reference marking at 0° and 180° and reference marking for axis of placement

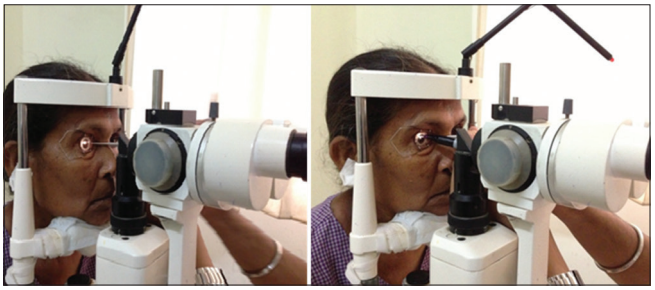


Figure 8: Reference marking on axis in upright position to avoid cyclotorsion

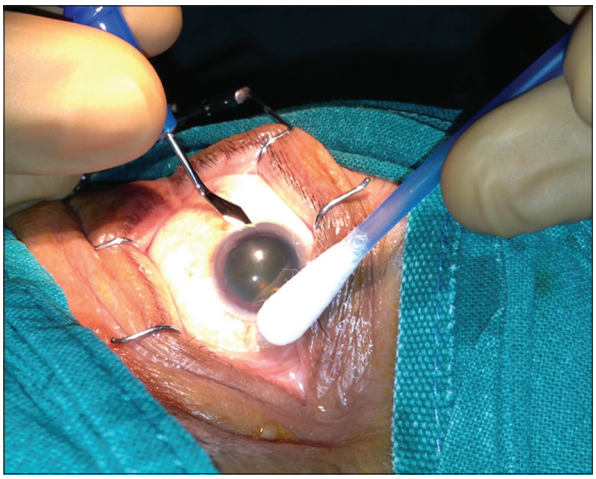


Figure 9: Clear corneal temporal incision

e. Foldable toric posterior chamber IOL (PCIOL) are put in cases with astigmatism of more than 2.5 D (Figure 5). Pre-operative corneal reference marking was done on the slit lamp with patient sitting in the upright position to avoid cyclotorsion (Figure 12). On table, the desired axis was marked. Toric lens was inserted and positioned 10° degrees before the desired axis marking. Viscoelastic substance (VES) was aspirated out which

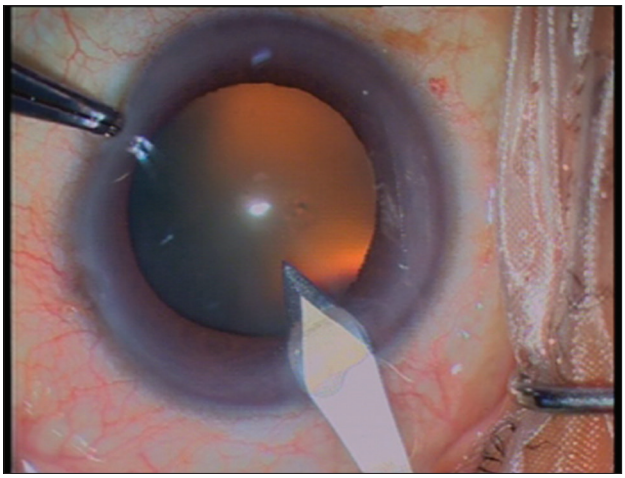


Figure 10: Incision on steep axis

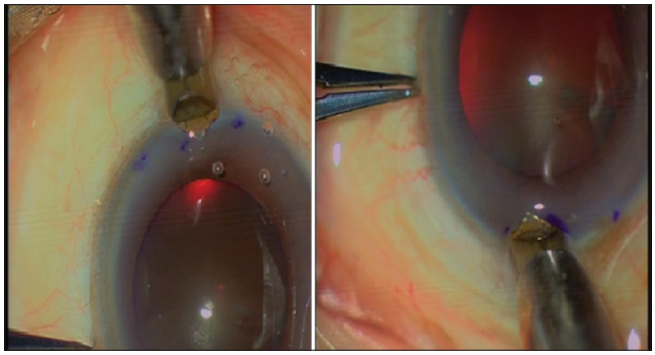


Figure 11: Limbal relaxing incision

caused certain degree to clockwise forward rotation of the lens and the remaining rotation till the desired axis was done manually with the help of a dialler.

f. AK was an alternative cheaper option in patients with astigmatism of more than 2.5 D (Figure 13). Axis marking was done preoperatively on the slit lamp. Before starting of the surgery preferably under topical anesthesia, single or paired arcuate incision on the cornea was made depending on nomogram and degree of astigmatism.

Surgery was performed by making clear corneal temporal incision with a 2.8 mm keratome and the whole procedure was done from this entry (Figure 6). Side port made at 90° from main incision, VES injected in anterior chamber, capsulorhexis done with no. 26 bent needle/cystitome. Hydrodissection done, phaco 1 used and trenching done, nucleus divided into 2, phaco 2 used and nucleus emulsified by stop and chop method, cortex I/A done, polishing of posterior capsule done, VES injected, foldable hydrophilic PCIOL inserted in the bag or a foldable Toric PCIOL at the desired axis, air bubble injected. Stromal hydration of all parts and main wound done with 0.1% intracameral moxifloxacin, e/d septidine, e/d predmet and e/oint chlorapplicap put, eye patching done.

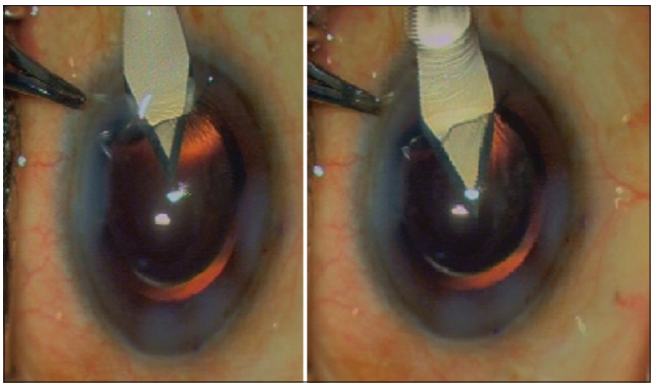


Figure 12: Opposite clear corneal incision

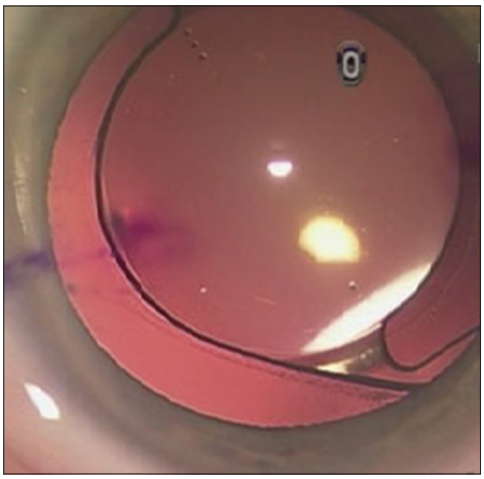


Figure 13: Toric lens insertion on axis

RESULTS

About 30 eyes underwent phacoemulsification cataract surgery with clear corneal temporal incision that had no pre-operative astigmatism. As shown in Table 1, We achieved mean residual astigmatism of 0.24 D and standard deviation (SD) of 0.22.

Whereas studies conducted by Ozkut, Nikola Susic and Mohammad Pakravan[24,25] achieved mean residual astigmatism of 0.88 D, 1.06 D, 0.73 D, respectively, and their SD achieved was 0.82, 0.83 and 0.46, respectively, in their studies has been shown in Table 1. We had chosen eyes with neutral astigmatism for this procedure.

Around 30 eyes underwent cataract surgery with incision on steep axis who had pre-operative astigmatism of ≤0.75 D. In our study, mean residual astigmatism was 0.18 D and SD was 0.21 as shown in Table 2. This study conducted by Gonçalves and Rodrigues[26] had mean residual astigmatism of 0.89 D and SD of 0.80.

30 eyes which underwent LRI procedure with phacoemulsification by clear corneal incision had

astigmatism between 0.75 and 1.50 D in our study. The mean residual astigmatism was 0.18 D and SD achieved was 0.21 with $P < 0.05$ in our study. In a similar study conducted by Carvalho *et al.*, and Bayramlar *et al.*,[27,28] they achieved a mean residual astigmatism of 1.02 D and 1.59 D respectively with the SD of 0.6 and 1.28with a $P < 0.05$ and <0.001, respectively, as been shown in Table 3.

We preferred with patients with astigmatism of 1.50 D-2.50 D to undergo OCCI procedure as the previous studies conducted had suggested a good result with this procedure with above astigmatism.

30 eyes which were subjected to OCCI with phacoemulsification with clear corneal temporal incision achieved mean residual astigmatism of 0.37 D and SD of 0.27 with $P < 0.05$ (Table 8).

As been documented in Table 4, studies conducted by Khokhar *et al.*, Bazzazi *et al.*, and Qammar and Mullaney[29-32] mean residual astigmatism documented was 0.91 D, 1.19 D, 2.02 D and SD was 0.54, 0.64 and 1.04, respectively (Table 7).

Table 3: Age distribution

Age	Type of Incision					
	Neutral axis	Steep axis	LRI	OCCI	Toric lens	AK
	Count (%)	Count (%)	Count (%)	Count (%)	Count (%)	Count (%)
26-40	2 (6.667)	2 (6.67)	4 (13.33)	0 (0)	0 (0)	0 (0)
41-55	9 (30)	7 (23.33)	6(20)	14 (40)	5 (16.666)	10 (33.333)
55-75	18 (60)	21 (70)	20 (66.66)	16 (60)	25 (83.333)	10 (33.33)
>75	1 (3.333)	0 (0)	0 (0)	0 (0)	0 (0)	10 (33.33)

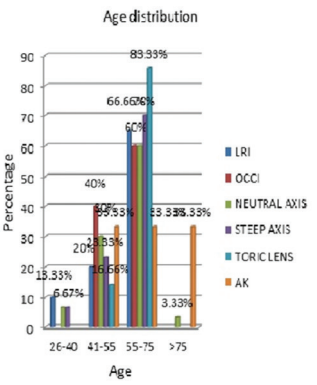
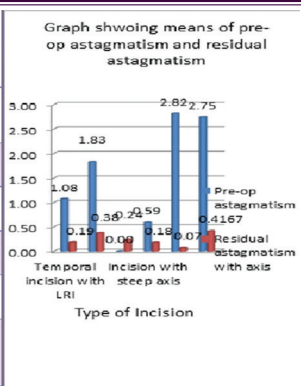


Table 4: Comparison of pre-operative astigmatism and residual astigmatism with axis

Type of incision	Pre-op astigmatism		Residual astigmatism with axis		t-value	p-value
	Mean	Std	Mean	Std		
Clear corneal temporal incision with neutral axis	0.000	0.000	0.2417	0.22248	-5.950	<0.05
Incision with steep axis	0.5917	0.17960	0.1833	0.21709	7.527	<0.05
Temporal incision with LRI	1.0750	0.21613	0.1875	0.21267	11.384	<0.05
Incision on steep axis with OCCI	1.8250	0.26484	0.3750	0.27003	17.759	<0.05
Temporal incision with toric lens	2.8214	0.23780	0.714	0.12199	22.543	<0.05
Incision on steep axis AK	2.7500	0.2500	0.4167	0.38188	7.000	<0.05 (0.020)



Foldable toric IOL are a better modality than AK procedure; we performed AK on 30 patients and 30 patients underwent clear corneal temporal incision with toric lens implantation on desired axis. AK is a cheap and easy procedure to perform as compared to foldable toric PCIOL which cost more, but we preferred toric lenses over AK on the basis of better outcome, lesser pain, reliability, and safety.

30 eyes which underwent foldable toric PCIOL procedure had mean residual astigmatism of 0.71 D and SD was 0.12 with $P < 0.05$. Mendicute *et al.*,[33,34] in their study had mean residual astigmatism of 0.62 D and SD of 0.46 with $P < 0.01$, as shown in Table 9.

30 eyes which were subjected to AK procedure had mean residual astigmatism of 0.41 D and SD of 0.38 with $P = 0.02$. Titiyal *et al.*,[35,36] in their study had got mean residual astigmatism of 1.26 D and SD of 0.54 with $P = 0.067$, as shown in Table 10.

DISCUSSION

There are numerous techniques for dealing with astigmatism both during and after cataract surgery. Good uncorrected postoperative distance visual acuity can be obtained for a high percentage of cataract patients with pre-existing corneal astigmatism. Corneal astigmatism can be treated effectively at the time of cataract surgery with either

Table 5: Comparison of clear corneal temporal incision with other studies

Study comparison	Pre-op astigmatism		Residual astigmatism with axis		p-value
	Mean	Std	Mean	Std	
Our Study	0	0	0.2417	0.22248	<0.05
yelda ozkut,Gurkan erdogen	0.74	0.45	0.88	0.82	
Borasio E,Mehta JS	0.78	0.51	0.74	0.68	
Nikola susic, Jaseuka Brajkovic	0.72	0.57	1.06	0.83	
Mohammad pakravan,Homayoun	0.63	0.48	0.73	0.46	<0.0001

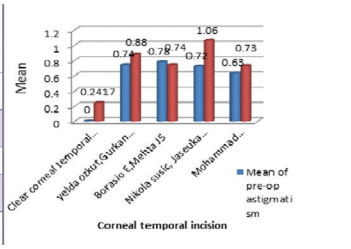


Table 6: Comparison of incision on the steep axis

	Pre-op astigmatism		Residual astigmatism with axis		p-value
	Mean	Std	Mean	Std	
Our Study Incision with steep axis	0.5917	0.1796	0.1833	0.21709	<0.05
Goncalves FP,Rodrigurs AC	1.06	0.65	0.89	0.8	

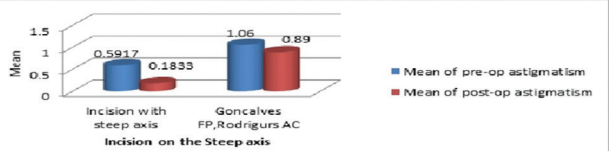


Table 7: Comparison of limbal relaxing incision on steep meridian with temporal clear corneal incision

	Pre op astigmatism		Residual astigmatism with axis		p-value
	Mean	Std	Mean	Std	
Our Study Temporal incision with LRI	1.075	0.21613	0.1875	0.21267	<0.05
Carvalho MJ,Suzuki SH	1.93	0.58	1.02	0.6	<0.05
Bayramlar,Borazan M	3.31	1.5	1.59	1.28	<0.001

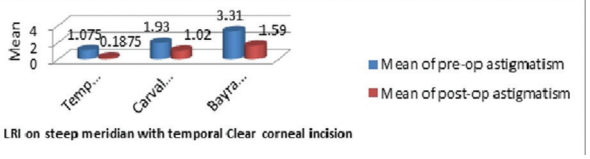


Table 8: Comparison of opposite clear corneal incision opposite to incision on the steep meridian

	Pre-op astigmatism		Residual astigmatism with axis		p-value
	Mean	Std	Mean	Std	
Temporal incision with OCCI	1.825	0.26484	0.375	0.27003	<0.05
Khobhar S,Lohiya P	2.51	0.92	0.91	0.54	
Ben simon GJ,Desatnik H	2.6		1.4	-	
Bazzazi N, Barazandeh B	1.74	0.86	1.19	0.64	0.009
Qanmar A, Mullaney	3.26	1.03	2.02	1.04	

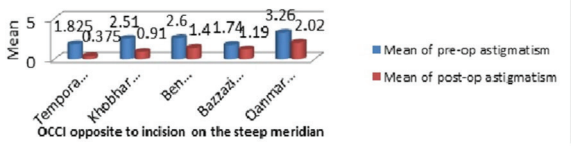


Table 9: Comparison of toric intraocular lens

	Pre-op astigmatism		Residual astigmatism with axis		p-value
	Mean	Std	Mean	Std	
Incision with Toric lens	2.8214	0.23780	0.0714	0.12199	<0.05
Mendicute ,Ivigoyen,Ruiz	-1.75	0.71	-0.62	0.46	<0.01
Mendicute ,Ivigoyen	-2.34	1.28	-0.72	0.43	<0.01

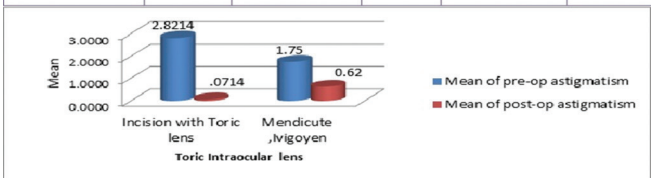
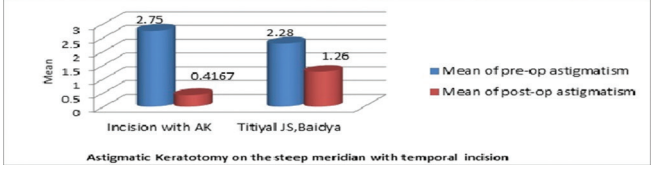


Table 10: Comparison of astigmatic keratotomy on the steep meridian with temporal incision

	Pre-op astigmatism		Residual astigmatism with axis		p-value
	Mean	Std	Mean	Std	
Incision with AK	2.75	0.25	0.4167	0.38188	0.02
Titiyal JS,Baidya	2.28	0.89	1.26	0.54	0.067
Kulkarni A, Mataftsi A	2.88		1.89		



foldable toric PCIOLs, corneal or LRI or OCCI or AK or combination of all. There are advantages and disadvantages to each method. The appropriate patient-based plan of either one or a combination of these different surgical techniques can provide a greater ability to correct cylindrical errors intra-operatively, achieving improved visual acuity, and visual quality independent of spectacles. Many studies have demonstrated that temporal incision induces least astigmatism, the value of 0.28 D to 0.50 D post-operative,[37,38] probably be due to the fact that the temporal limbus is farther from the visual axis than the superior limbus.[24] It is effective to create a clear corneal incision at the steep corneal axis, whether superiorly, temporally, or obliquely, to profit the flattening effect of the incision which can help to reduce astigmatism along that axis. This approach is usually sufficient for most of the eyes.[39,25,26]

CONCLUSION

It should be kept in mind that postoperative keratorefractive surgery may also be available to enhance the condition of patients who achieve less-than-optimal astigmatic results. A small 2.8 mm corneal incision in phacoemulsification induces on average very small corneal refractive change, but differences were detected depending on the location of the incision.

SIA of the operating surgeon in our study was 0.30 D.

In our study, we compared our results to other studies which were done in the past which used similar modalities to tackle pre-operative astigmatism during cataract surgery.

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How to cite this article: Vidhan CD, Nita US, Sumita SK, Taran DW. Targeting Emmetropia in a Pseudophakic Eye: A Prospective Study. Int J Sci Stud 2016;3(12):217-224.

Source of Support: Nil, **Conflict of Interest:** None declared.