J Nepal Health Res Counc 2025 Oct-Dec; 23 (69):684-690

Changes in Corneal Curvature and Astigmatism After Phacoemulsification Surgery

Pramod Kumar Yadav,[1] Sabitri Bhatta,[1] Suresh Awasthi,[2] Sagun N Joshi,[3] Madhu Thapa,[3] Niraj Dev Joshi,[3] Arjun Sapkota,[4] Gauri Sr Shrestha[3]

[1]Geta Hospital, Kailali, Nepal, [2]Geta Eye Hospital, Kailali, Nepal, [3]B.P. Koirala Lions Center for Ophthalmic Studies, Institute of Medicine, Nepal, [4]Himalaya Eye Institute, Himalaya Eye Hospital,Nepal.

ABSTRACT

Background: This study aimed to investigate the relationship between anterior corneal curvature and astigmatism before and after phacoemulsification surgery.

Methods: A total of 90 eyes from 90 participants who underwent phacoemulsification with a 3.0 mm superior-temporal clear corneal incision were included in this longitudinal study. Each participant underwent a comprehensive ocular examination, including refraction and keratometry readings (k-readings) obtained using an automated keratometer on the IOL Master. Examinations were conducted preoperatively, on the first postoperative day, at one week, and four weeks postoperatively. The four-week postoperative refractive astigmatism was estimated and predicted with preoperative k-readings.

Results: The mean preoperative and postoperative refractive astigmatism was -0.74±0.49D and -0.36±0.18D, with a mean difference of -0.38±0.46D ($p<0.001$). The proportion of with-the-rule (WTR) astigmatism increased significantly at four weeks postoperatively (71.1%) compared to preoperatively (16.7%). Linear regression analysis showed that postoperative refractive astigmatism was not significantly influenced only by preoperative anterior k-readings obtained using the automated keratometer ($\beta=-0.046$; $p=0.77$).

Conclusions: A supero-temporal 3.0 mm clear corneal incision has shown stability in minimizing postoperative surgically induced astigmatism (SIA) in phacoemulsification cataract surgery. Postoperatively, posterior corneal curvature changes may attributes to surgically induced astigmatism which may be benefited by toric intraocular lens implantation (IOL) for better visual outcome.

Keywords: Auto refractometer; incision; keratometry-readings; phacoemulsification; surgically induced astigmatism.

INTRODUCTION

Phacoemulsification is one of the greatest advancements in surgical techniques, offering minimal invasiveness and improved postoperative visual outcomes. Surgically induced astigmatism (SIA) remains a common complication that can compromise visual quality.[1] SIA is influenced by factors such as incision size, shape, site, and preoperative astigmatism. Patients with 0.50 diopters (D) or less of astigmatism typically do not require spectacles for distance activities, whereas the need for spectacles increases with each additional diopter of astigmatism.[2,3] Supero-temporal clear corneal incisions (CCI) of 3.00 mm in phacoemulsification surgery have been reported to produce minimal surgically induced astigmatism (SIA).[4,5] This study aimed to investigate the relationship between anterior corneal curvature and astigmatism before and after phacoemulsification surgeryusing the automated keratometer mounted on the IOL Master. To the best of our knowledge, there have been no reports comparing curvature and refractive astigmatism in Nepalese eyes undergoing phacoemulsification surgery using both automated keratometer.

METHODS

This was a prospective, longitudinal and Hospital-based study carried in 112 consecutive participants undergoing phacoemulsification surgery between November 2015 and October 2016. Participants were recruited from the BPK Centre for Ophthalmic Studies, Institute of

Correspondence: Sabitri Bhatta, Geta Eye Hospital, Email: bhattasabitri1@gmail.com, Phone: +9779848434384.

Medicine, Nepal. This research was conducted in accordance with the tenets of the Declaration of Helsinki and was ethically approved by the Ethical Review Board of the Institute of Medicine, with registration number 19/2016. Verbal and written informed consent were obtained from all participants. The study included participants with age-related Immature cataracts and lens opacification classified as grade ≥3.0 on the Lens Opacities Classification System III (LOCS III), aged over 40. Exclusion criteria included cataracts affecting IOL power measurement, preoperative corneal astigmatism greater than 3.00D, lid abnormalities, previous refractive surgery, complications during or after cataract surgery, and unwillingness to participate. Diabetic participants were also excluded, as elevated blood glucose levels are associated with lens opacification and may alter the biomechanical properties of the cornea.

Almost 190 phacoemulsificatoin surgery were performed based on previous medical record by single phaco surgeon. Assuming 60 percent had immature cataract where ocular biometry could be performed by both IOL master and Ultrasound A-scan selected for surgery, the estimated sample size would be 112. The minimum sample size required to estimate a proportion with 95% confidence and using desired 5% margin of error was calculated using Z=1.96, p=0.5 and finite population correction for a monthly phaco population of N=112. Using the Finite population correction (FPC) after estimating a proportion of initial sample size using the formula, $n=n_0/(N+n_0-1/N)$.The calculated minimum required sample after correction was 87 eyes, 112 eyes were available during data collection and therefore sufficient for the further analysis.

After obtaining written informed consent, all patients underwent cataract surgery using clear corneal phacoemulsification with the 'Stop and Chop' technique, followed by foldable in-the-bag IOL implantation, performed by the cataract surgery was operated by single well experienced phaco and vitreo-retinal surgeon with clinical experience of more than 10 years. During the surgery, one drop of topical tropicamide 0.5% and xylocaine 4% was administered. A 3.00 mm temporal clear corneal incision was made, and an IOL was implanted in the capsular bag. Phacoemulsification surgery involved the use of a machine with an ultrasonic handpiece, equipped with a titanium or steel tip that vibrates at ultrasonic frequencies to emulsify the cataractous lens material. The lens was fragmented into smaller pieces to facilitate emulsification and cortical material aspiration. After the lens nucleus was emulsified, a dual irrigation-aspiration probe was used to remove the remaining peripheral cortical material. The surgery was performed through a small corneoscleral wound (2.2-3.2 mm). The foldable IOL was inserted using a lens injector through this small incision. No sutures were required due to the small incision size and two-level openings, which promote rapid healing with minimal astigmatism and faster visual recovery.

Participants were examined preoperatively and at 1 day (POD1), 7 days (POD7), and 30 days (POD30) postoperatively. A comprehensive eye examination was conducted for all participants undergoing phacoemulsification, which included intraocular pressure (IOP) measurement using a Goldmann-applanation tonometer, slit lamp biomicroscopy, and dilated fundus examination with a 90D lens (Volk, Japan). Automated keratometry was performed using the IOL Master (Partial Coherence Interferometry, Carl Zeiss Meditec AG, Jena, Germany) to obtain keratometry values, focusing on an aspheric profile within a central 2.3mm zone. The automated keratometer uses light reflection based on dual-beam partial coherence laser interferometry (PCI), arranging six hexagonal light points with a 2.3mm diameter from the air/tear film interface. Pre- and post-operative auto refraction were measured with the ARK-30 auto refractor (Nidek Co. LTD, Aichi, Japan). Subjective and objective refraction (Heine-Beta 200, Germany) were carried out preoperatively, on the first postoperative day, and after four weeks. A single optometrist measured each participant's keratometric values and performed refraction, ensuring consistency in techniques and analysis. The nuclear opalescence of the lens was graded using the LOCS III scale.[6] Corrected distance visual acuity (CDVA) was measured with a Snellen chart, and Snellen visual acuity was converted to the logarithm of the minimum angle of resolution (logMAR) for statistical analysis. Corneal astigmatism was classified as with-the-rule (WTR) for steep corneal curvature between 60° and 120°, against-the-rule (ATR) for curvature between 0° and 30° or between 150° and 180°, and all other cases as oblique astigmatism. The degree of astigmatism was categorized as normal (less than 1D), low (1-2D), moderate (2-4D), or high (greater than 4D). Corneal astigmatism was analyzed using the power vector method, converting corneal power (Ksteep @θ1 and Kflat @θ2) into Jackson cross-cylinder values with axes at 180° and 90° (J0) and at 45° and 135° (J45).[7] Surgically induced astigmatism (SIA) was calculated at each postoperative visit using polar value analysis.[8]

Patients were enrolled consecutively, and data were analyzed using SPSS 25.0 (SPSS Inc., Chicago, IL). A result was considered statistically significant if $p<0.05$. The Shapiro-Wilk test was used to assess the normality of the distribution of all parameters, allowing for comparisons between groups. Repeated measures one-way ANOVA was used to compare keratometric values preoperatively, on the first postoperative day, one week, and four weeks after phacoemulsification surgery. Bonferroni adjustments were applied for mean comparisons. Paired t-tests were conducted to compare preoperative and postoperative data.

RESULTS

A total of 112 eyes underwent pre-operative evaluation for phacoemulsification cataract surgery. Among these, 98 eyes (87.5%) met the eligibility criteria and were selected for cataract surgery, while 14 eyes (12.5%) were excluded at the pre-operative stage. Of the excluded eyes, 10 eyes were rejected due to incompatibility with the implantation of the Alcon intraocular lens (A-constant 118.4), 2 eyes were cancelled because of elevated fasting blood sugar levels (>150 mg/dl), and 2 eyes did not report for surgery. Finally, 90 eyes of 90 participants were selected for further analysis. Among 90 subjects of 90 eyes, 41 (45.00%) were taken for further analysis by IOL Master and 49 (54.4%) by the A-scan. The mean age of the 90 participants (90 eyes) enrolled in the study was 68.58±7.36 years, with 35(38.9%) males and 55 (61.1%) females. The Shapiro-Wilk test confirmed that k-readings and astigmatism values followed a normal distribution. The demographic characteristics of the participants are summarized in **Table 1**. Preoperatively, the mean spherical equivalent (SE) was -1.85±2.05D. The preoperative and postoperative VA were 0.75±0.29 and 0.16±0.10 LogMAR respectively. The types of preoperative and postoperative astigmatism, including with-the-rule (WTR), against-the-rule (ATR), and oblique astigmatism, are shown in **Table 2**. As shown in **Figure 1**, the ratio of WTR astigmatism increased significantly at four weeks postoperatively (71.1%) compared with preoperatively (16.7%). Conversely, the ratio of ATR decreased from 82.2% preoperatively to 25.6% postoperatively. The proportion of oblique astigmatism increased from 1.1% preoperatively to 3.3% at four weeks postoperatively. The mean preoperative and four-week postoperative corneal astigmatism were -0.74±0.49D and -0.36±0.18D, respectively, with a mean difference of -0.38±0.46D ($p<0.001$), indicating minimal postoperative astigmatism with a superior temporal incision. Using repeated measures one-way ANOVA, postoperative corneal astigmatism at each follow-up is shown in **Figure 2**, demonstrating a significant reduction in postoperative astigmatism at the first and four-week follow-up visits after phacoemulsification.

The relationship between average k-reading and corneal astigmatism within the groups was further analyzed using a linear regression model. One month postoperative astigmatism was treated as the dependent variable and average k-readings as the independent variable. The regression analysis, as shown in **Figure 3**, revealed that the four-week postoperative astigmatism was not significantly affected by the preoperative k-reading from the automated keratometer (ß=-0.046; p=0.77), indicating that the posterior corneal curvature is also the main factor for surgically induced astigmatism. This results also indicates that superior temporal 3.00mm clear corneal incision is the most effective method to minimize postoperative surgically induced astigmatism in phacoemulsification surgery. Repeated measures ANOVA were used to compare the means of three or more groups when participants were in the same group across different time points. The time-dependent changes in corneal curvature, as measured by k-readings preoperatively, on the first postoperative day, one week postoperatively, and one month postoperatively with automated keratometers, is shown in **Tables 3**. These tables show no statistical difference between the various intervals.

Table 1. Demographic characteristics of participants in the study.

Characteristics	Automated keratometer (n=90)
Age (mean±SD)	68.58±7.36
Sex, n (%)	
Male	35(38.9%)
Female	55 (61.1%)
LOCS III (mean±SD)	4.56±1.45
UCDVA, logMAR (mean±SD)	0.75±0.29
SE (mean±SD)	-2.27±1.64

Table 2. Types of preoperative and four weeks postoperative refractive astigmatism (n=90)

Astigmatism	Preoperative	Four weeks postoperative
With the rule	15 (16.7%)	64 (71.1%)
Against the rule	74 (82.2%)	23 (25.6%)
Oblique	1 (1.1%)	3 (3.3%)

Table 3. Pair wise Comparisons of K-reading measured in automated keratometer in different intervals by using repeated measure one way ANOVA.

K-reading (I)	(J) K-reading effect	Mean difference (I-J) ±SD	Sig .[b]
	2	-0.03±0.01mm	1.00
1	3	-0.02±0.01mm	0.61
	4	-0.05±0.01mm	1.00
2	3	-0.02±0.01	1.00
3	4	0.01±0.01	0.39

Based on estimated marginal means

*. The mean difference is significant at the .05 level

[b]ANOVA using post hoc analysis after Bonferroni adjustment for multiple comparisons

1=preoperative average K-reading by automated keratometer

2=first postoperative average K-reading byautomated keratometer

3=one week postoperative average K-reading byautomated keratometer

4=one month postoperative average K-reading by automated keratometer

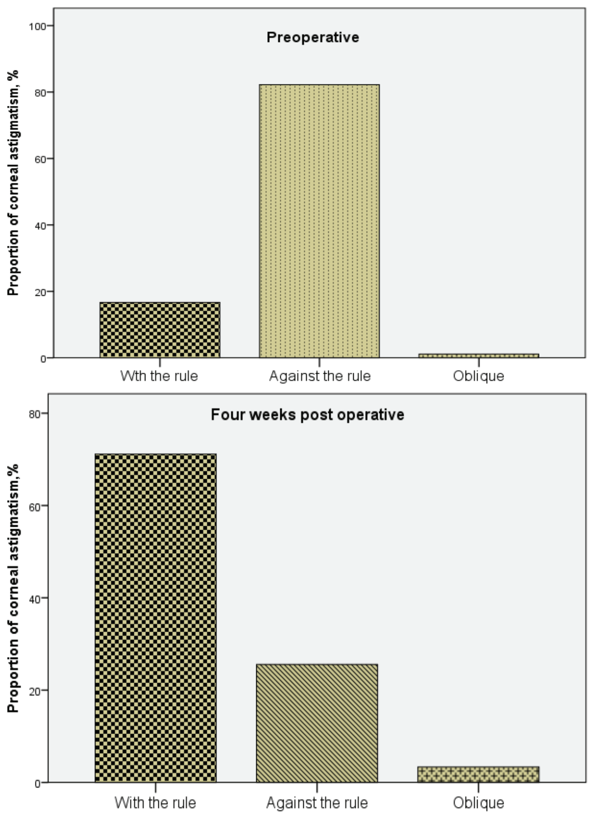

Figure 1. The distribution of refractive astigmatism preoperatively and four weeks postoperatively.

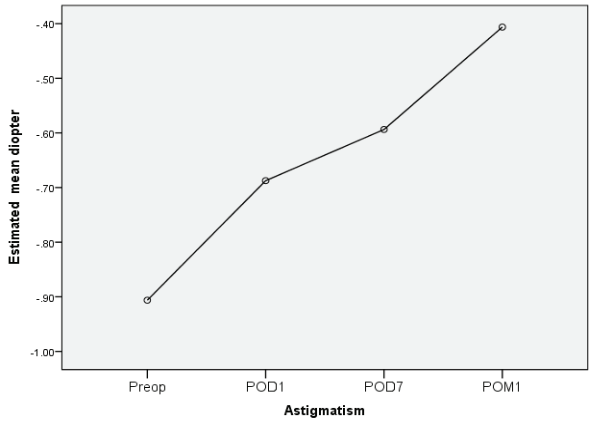

Figure 2. Time-dependent changes in refractive astigmatism, after phacoemulsification cataract surgery with superio-temporal clear corneal incision of 3mm. P<0.05, shows statistically significant differences between the preoperative and postoperative refractive astigmatism data were found for the refractive error. Preop, preoperative; POD1, postoperative day 1; POD7, postoperative day 7; POM1, one month postoperative.

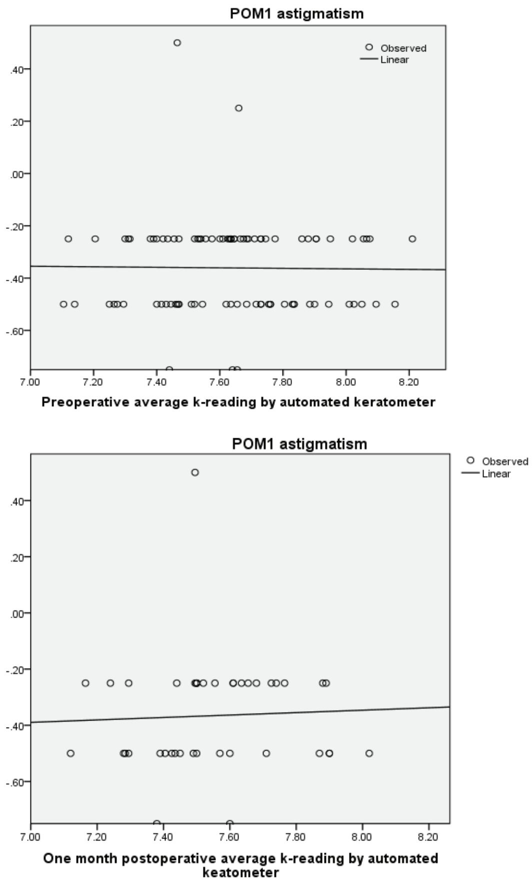

Figure 3. Regression plot between preoperative average k-reading, one month postoperative k-reading measured by automated keratometer as a predictor of one month postoperative refractive astigmatism;*statistically significant at p<0.05 for 95% confidence interval. POM1, one month postoperative.

DISCUSSION

Accurate intraocular lens (IOL) implantation, along with careful selection of the incision type and location for small incision cataract surgery, plays a crucial role in reducing surgically induced astigmatism and enhancing postoperative visual quality. This study examined whether there was a significant change in anterior corneal parameters following phacoemulsification cataract surgery with a 3.00mm temporal clear corneal incision, as well as the effect on postoperative astigmatism. Follow-up after cataract surgery is essential to monitor visual recovery, detect complications, and ensure corneal curvature and astigmatism stabilize for optimal visual outcomes. For true spectacle independence, patients need to have ≤ 0.50D of astigmatism after surgery. Several options are available for reducing corneal astigmatism during cataract surgery, and surgeons should choose an approach based on the degree of preoperative corneal astigmatism. Placing the clear corneal incision on the steep meridian in patients with ≥1.0D of preoperative astigmatism produces a flattening effect on the corneal curvature, which helps minimize postoperative astigmatism.[9,10,11]

The mean preoperative astigmatism in participants in this study was -0.74±0.49D, which aligns with previous studies where preoperative astigmatism values were under -1.25D.[12,13] This study demonstrated that the average postoperative surgically induced astigmatism was -0.38±0.46D using a 3.0mm clear corneal incision, a value consistent with prior studies where postoperative astigmatism was approximately within the range of 0.50D. Additionally, this study suggests that an average of 0.5D of astigmatism is typically expected postoperatively in keratometry readings, which can be used for prescribing based on visual performance.[14,15]

This study explored changes in corneal curvature following a 3.00mm superior-temporal clear corneal incision, with most participants exhibiting with-the-rule (WTR) astigmatism postoperatively. These differences may be due to the varying types of astigmatism on the anterior and total corneal surfaces resulting from superior-temporally placed clear corneal incisions. Temporal incisions tend to induce with-the-rule astigmatism, while superior incisions lead to against-the-rule changes. Consequently, the refractive effect of the superior-temporal clear corneal incision did not show any significant change from day one to one week post-phacoemulsification.[16] The possible reason for the postoperative with-the-rule astigmatism may be the overestimation of the anterior corneal curvature, though no statistically significant differences in corneal astigmatism were found at any follow-up using the automated keratometer. Another reason may be the lack of estimation of posterior corneal curvature during keratometry readings. These results indicate that the 3.00mm superior-temporal clear corneal incision in phacoemulsification is an ideal and stable choice, resulting in minimal changes in corneal shape and minimal postoperative astigmatism.[17] In this study, the 3.0mm superior-temporal incision demonstrated significantly less total keratometric cylinder postoperatively, with non-significant changes in keratometry readings and less surgically induced cylinder at the first postoperative day and one week postoperatively. These findings are consistent with previous studies.[18] Other non-significant changes in postoperative k-readings may be due to the failure to account for the posterior corneal surface, which could affect the reliability of postoperative k-readings and SIA values.[19] Previous studies also suggest that postoperative refraction after uncomplicated cataract surgery is generally stable one week postoperatively, which may explain the lack of significant changes in corneal curvature and astigmatism.[20] The high frequency of surgically induced astigmatism is associated with nasal incisions, which might be influenced by their proximity to the optical center, the approach angle to the cornea, and stretch or distortion of the cornea during surgery. From this study, it is suggested that k-reading value from automated keratometer value should not be interchangeable with manual keratometer for IOL power calculation and minimizing the postoperative astigmatism, and this study is suggested in previous study done by Bhatta et al.[21] The manual keratometer requires the user to align the keratometer mires along the principal meridians and corneal radius, and are highly operator-dependent.

The limitations of this study include the small sample size, short follow-up period, and the lack of analysis on changes in posterior corneal curvature, which may affect the estimation of the type and magnitude of postoperative astigmatism. This aspect will be addressed in future research. Additionally, future studies will incorporate new investigative procedures, such as Pentacam, to assess changes in anterior, posterior, and total corneal curvature, along with high-order aberrations (HOAs) after surgery, and to explore the relationship between changes in curvature and HOAs.

CONCLUSIONS

Superior-temporal clear corneal incisions of 3.00mm are the optimal site for minimizing postoperative surgically induced astigmatism in phacoemulsification cataract surgery, with no significant changes in corneal curvature. Corneal astigmatism within 1.00 D was observed in a significant number of participants, indicating that toric IOL implantation could enhance visual quality and stability while minimizing surgically induced astigmatism.

ACKNOWLEDGEMENTS

I am thankful to all the participants, administrative, and clinical staffs to carry out this study.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Kağnici DB, Kocatürk T, Çakmak H, Dündar SO. Surgically Induced Corneal Astigmatism Following Cataract Surgery. 2015;(May):47-53.doi: https://doi.org/10.4236/ojoph.2015.52008

2. Rubenstein JB, Raciti M. Approaches to corneal astigmatism in cataract surgery. 2013;24(1):30-34. doi: https://doi.org/10.1097/ICU.0b013e32835ac853

3. Wilkins MR, Allan B, Rubin G, Iol M, Group S. Spectacle use after routine cataract surgery. 2009;(D):1307-1312. doi: https://doi.org/10.1136/bjo.2008.151829

4. Wang X. Study of Postoperative Astigmatism Between Superior and Temporal Clear Corneal Incision in Phacoemulsification. 2023;2(1):5-9.

5. Mallik VK, Kumar S, Kamboj R, Jain C, Jain K, Kumar S. *Comparison of Astigmatism Following Manual Small Incision Cataract Surgery: Superior versus Temporal Approach*. Vol 4.; 2012. doi: https://doi.org/10.3126/nepjoph.v4i1.5851

6. Chylack LT, Wolfe JK, Singer DM, Leske MC, Bullimore MA, Bailey IL, et al. The lens opacities classification system III. Archives of ophthalmology. 1993 Jun 1;111(6):831-6. doi: https://doi.org/10.1001/archopht.1993.01090060119035

7. Thibos LN, Horner D. Power vector analysis of the optical outcome of refractive surgery. *J Cataract Refract Surg*. 2001;27(1):80-85. doi: https://doi.org/10.1016/S0886-3350(00)00797-5

8. Naeser K, Hjortdal J. Polar value analysis of refractive data. *J Cataract Refract Surg*. 2001;27(1):86-94. doi: https://doi.org/10.1016/S0886-3350(00)00799-9

9. Buckhurst PJ, Wolffsohn JS, Davies LN, Naroo SA. Surgical correction of astigmatism during cataract surgery. *Clin Exp Optom*. 2010;93(6):409-418. doi: https://doi.org/10.1111/j.1444-0938.2010.00515.x

10. Rho CR, Joo CK. Effects of steep meridian incision on corneal astigmatism in phacoemulsification cataract surgery. *J Cataract Refract Surg*. 2012;38(4):666-671. doi: https://doi.org/10.1016/j.jcrs.2011.11.031

11. Grunstein LL, Miller KM. Astigmatism management at the time of cataract surgery. *Expert Rev Ophthalmol*. 2011;6(3):297-305. doi: https://doi.org/10.1586/eop.11.25

12. Nikose AS, Saha D, Laddha PM, Patil M. Surgically induced astigmatism after phacoemulsification by temporal clear corneal and superior clear corneal approach: A comparison. *Clin Ophthalmol*. 2018;12:65-70. doi: https://doi.org/10.2147/OPTH.S149709

13. Ferrer-Blasco T, Montés-Micó R, Peixoto-de-Matos SC, González-Méijome JM, Cerviño A. Prevalence of corneal astigmatism before cataract surgery. *J Cataract Refract Surg*. 2009;35(1):70-75. doi: https://doi.org/10.1016/j.jcrs.2008.09.027

14. Khan MI, Muhtaseb M. Prevalence of corneal astigmatism in patients having routine cataract surgery at a teaching hospital in the United Kingdom. *J Cataract Refract Surg*. 2011;37(10):1751-1755. doi: https://doi.org/10.1016/j.jcrs.2011.04.026

15. Gross RH, Miller KM. Corneal astigmatism after phacoemulsification and lens implantation through unsutured scleral and corneal tunnel incisions. *Am J Ophthalmol*. 1996;121(1):57-64. doi: https://doi.org/10.1016/S0002-9394(14)70534-3

16. Nielsen PJ. Prospective evaluation of surgically induced astigmatism and astigmatic keratotomy effects of various self-sealing small incisions. *J Cataract Refract Surg*. 1995;21(1):43-48. doi:

https://doi.org/10.1016/S0886-3350(13)80478-6

17. Gautam N, Kumar S, Shahnawaz A. Postoperative Corneal Astigmatism Following Cataract Phacoemulsification Using Corneal Supertemporal Incision : Report From A Tertiary Care Hospital in Bihar. Published online 2023:637-640. doi:10.47009/jamp.2023.5.3.133

18. García-López V, García-López C, de Juan V, Martin R. Análisis del astigmatismo inducido en la cirugía de cataratas: comparación de dos métodos polares. *J Optom*. 2017;10(4):252-257. doi: https://doi.org/10.1016/j.optom.2016.11.001

19. Klijn S, van der Sommen CM, Sicam VADP, Reus NJ. Value of posterior keratometry in the assessment of surgically induced astigmatic change in cataract surgery. *Acta Ophthalmol*. 2016;94(5):494-498. doi: https://doi.org/10.1111/aos.13003

20. De Juan V, Herreras JM, Pérez I, Morejón Á, Río-San Cristóbal A, Martín R, et al. Refractive stabilization and corneal swelling after cataract surgery. Optometry and Vision Science. 2013 Jan 1;90(1):31-6. doi: https://doi.org/10.1097/OPX.0b013e318278fc44

21. Bhatta S, Narayan Joshi S, Thapa M, Awasthi S, Shankar Shrestha G, Dev Joshi N. Prediction and Estimation of Postoperative Refractive Error in Phacoemulsification: Using Ultrasound A-Scan and Intra Ocular Lens Master. *J Nepal Health Res Counc*. 2024;22(03):494-501. doi: https://doi.org/10.33314/jnhrc.v22i03.4854