

# Statistical Analysis of Factors Affecting Surgically Induced Astigmatism Following Trabeculectomy

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**Purpose:** To objectively evaluate surgically induced astigmatism (SIA) after trabeculectomy with mitomycin C and investigate the relationships between SIA and various factors.

**Patients and Methods:** This retrospective study included the right eyes of 66 consecutive patients who underwent standard trabeculectomy performed in the superior temporal quadrant for the first time by a single surgeon. Keratometry recordings made before surgery and 3 months after surgery were collected to calculate the SIA in each patient. The arithmetic mean of SIA (M-SIA) and the centroid of SIA (C-SIA) were determined using vector analysis. The relationships between the magnitude of SIA and the following possible related factors were assessed: age, sex, pre-operative corneal astigmatism, pre-operative intraocular pressure (IOP), 3-month postoperative IOP, pre-operative best-corrected visual acuity (BCVA), 3-month postoperative BCVA, the number of total scleral flap sutures (T-SFS), the number of leftover scleral flap sutures without laser suture lysis at 3 months postoperatively (L-SFS), shape of the scleral flap (triangle or trapezoid), and incision type of the conjunctival flap (fornix- or limbal-based).

**Results:** The mean ( $\pm$  standard deviation) M-SIA was  $1.00 \pm 0.85$  D, and the mean C-SIA was  $0.34 \pm 1.28$  D at  $104^\circ$ . The direction of C-SIA showed a trend of corneal steepening to the superior temporal location, in the direction of the scleral flap location. There were significant correlations of the magnitudes of SIA with the number of T-SFS ( $P = 0.001$ ) and the number of L-SFS ( $P < 0.001$ ).

**Conclusion:** Trabeculectomy induced SIA in the direction of the scleral flap location, and scleral sutures are significantly associated with the SIA. The scleral suture may play a key role in steepening the cornea toward the scleral flap direction in post-trabeculectomy patients.

**Keywords:** SIA, trabeculectomy, influencing factor, scleral flap suture, glaucoma

## Introduction

Glaucoma is one of the leading causes of blindness in developed countries,<sup>1</sup> and lowering intraocular pressure (IOP) is the only therapeutic approach that reduces the risk of glaucomatous vision loss.<sup>2,3</sup> Glaucoma surgery is necessary when the IOP is poorly controlled with medical therapies, and trabeculectomy is thought to be the standard surgery because of its excellent IOP-lowering effect. However, it is also known that trabeculectomy causes a certain amount of surgically induced astigmatism (SIA),<sup>4-17</sup> resulting in decreased visual acuity.

Several possible explanations for SIA following trabeculectomy have so far been advocated, such as posterior placement of the incision,<sup>4</sup> tight scleral suturing,<sup>4,7,8</sup> removal of tissue under the scleral flap,<sup>5</sup> excessive cautery,<sup>6-8</sup> pressure of the eyelid and large filtering bleb on the cornea,<sup>13</sup> delayed wound healing caused by the use of mitomycin C,<sup>9</sup> lower postoperative IOP,<sup>11,13,15</sup> and the surgical site,<sup>15</sup> but the exact mechanism of SIA is not clearly understood. Thus, the purpose of this study was to objectively evaluate SIA after trabeculectomy with mitomycin C and to investigate the relationships between SIA and various background factors.

## Materials and Methods

This retrospective study included the right eyes of 66 consecutive patients who underwent standard trabeculectomy performed in the superior temporal quadrant for the first time by a single surgeon (N.S.) at Nippon Medical School Hospital between January 2015 and December 2019. This study did not include cases of simultaneous cataract surgery. Patients with a history of any corneal disorder such as corneal degeneration or corneal transplantation were also excluded.

The recorded data including keratometry recordings, IOP, and the best-corrected visual acuity (BCVA) before surgery and 3 months (2–4 months) after surgery were collected by chart review. Keratometry was recorded by an autorefractor keratometer (Nidek, TONOREF II, Gamagori, Aichi, Japan). The IOP was measured by Goldmann applanation tonometry. The BCVA measured using a decimal visual acuity chart was converted to the logarithm of the minimum angle of resolution (logMAR VA). Surgical procedural information, including the number of scleral flap sutures, status of laser suture lysis following trabeculectomy, shape of the scleral flap (triangle or trapezoid), and the incision type of the conjunctival flap (fornix- or limbal-based), was also collected.

The current study was conducted in accordance with the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of Nippon Medical School Hospital (No. R1-07-1165). Written, informed consent for trabeculectomy was obtained from all patients after explaining the nature of the procedure and the possible consequences. The ethics committee waived the requirement for the patients' informed consent regarding the use of their medical record data; instead, the protocol was posted on the website of the hospital to notify participants of the study.

## Surgical Procedure

All surgeries were performed by a single surgeon (N.S.). A fornix- or limbal-based conjunctival flap was made, followed by a triangular or trapezoidal (base approximately 2–3 mm and height 2–3 mm) single half-layer scleral flap in the superior temporal quadrant. Mitomycin C (0.4 mg/mL) was applied for 4 minutes, followed by rinsing with 400 mL of balanced salt solution. A scleral window of approximately 2.0 mm x 0.5 mm was created using a straight knife and small scissors. After a peripheral iridotomy was performed, the scleral flap was closed with several interrupted, 10–0 nylon, watertight sutures. The conjunctiva was then readapted with 10–0 nylon sutures. Laser suture lysis was conducted within a month postoperatively on the basis of the IOP value and the bleb condition. Conjunctival sutures were removed around 2–3 weeks after the surgery. In all cases, 1.5% levofloxacin and 0.1% betamethasone were applied topically, 4 times daily, for 3–4 weeks postoperatively.

## Assessment of Surgically Induced Astigmatism

SIA was calculated using the SIA Calculator Version 2.1, a free software program, developed by Saurabh Sawhney and Aashima Aggarwal (<http://www.insighteyeclinic.in/SIAcalculator.php>) based on the vector analysis algorithm.<sup>18,19</sup> The arithmetic mean of SIA (M-SIA), which is the mean of only the magnitude of SIA, and the centroid of SIA (C-SIA), which is the mean SIA vector considering not only magnitude, but also direction, were determined. The magnitudes of SIA are expressed as means  $\pm$  standard deviation. The distributions of SIAs were then displayed as double-angle plots using the double-angle-plot-tool for astigmatism available on the American Society of Cataract and Refractive Surgery (ASCRS) Website (<https://ascrs.org/tools/astigmatism-double-angle-plot-tool>).<sup>20</sup>

## Statistical Analysis

Descriptive statistics for all demographic and clinical variables were calculated. All continuous data are expressed as mean  $\pm$  standard deviation values. Spearman's rank correlation test was used to assess possible correlations between SIA magnitude and continuous variables: age, pre-operative corneal astigmatism, pre-operative IOP, 3-month postoperative IOP, pre-operative BCVA, 3-month postoperative BCVA, the number of total scleral flap sutures (T-SFS), and the number of leftover scleral flap sutures without laser suture lysis at 3 months postoperatively (L-SFS). The Mann Whitney *U*-test was conducted to determine significant differences in SIA magnitude between pairs of the following conditions: sex (male or female), shape of the scleral flap (triangle or trapezoid), and incision type of the conjunctival flap (fornix- or

**Table 1** Demographic Characteristics of the Study Participants

Sex (male/female)	36/30
Age (y)	62.1 ± 12.7 (26 to 86)
Glaucoma type	38 POAG, 24 SOAG, 4 PACG
Preoperative IOP (mmHg)	26.6 ± 11.5 (11 to 59)
Postoperative 3 months IOP (mmHg)	11.6 ± 5.0 (3 to 25)
Preoperative BCVA (logMAR)	0.19 ± 0.41 (−0.08 to 2)
Postoperative 3 months BCVA (logMAR)	0.28 ± 0.55 (−0.08 to 2.3)
Preoperative corneal astigmatism (dioptres)	0.95 ± 0.70 (0 to 4)
Shape of scleral flap	37 Triangle, 29 Trapezoid
Type of conjunctival flap	38 Fornix-, 28 Limbal-based
Number of total SFS (%)	
3	50 (75.8%)
4	11 (16.7%)
5	4 (6.1%)
8	1 (1.5%)
Number of leftover SFS without LSL (%)	
0	36 (54.5%)
1	15 (22.7%)
2	5 (7.6%)
3	6 (9.1%)
4	2 (3.0%)
5	2 (3.0%)

**Note:** Values are the mean ± standard deviation (range) values.

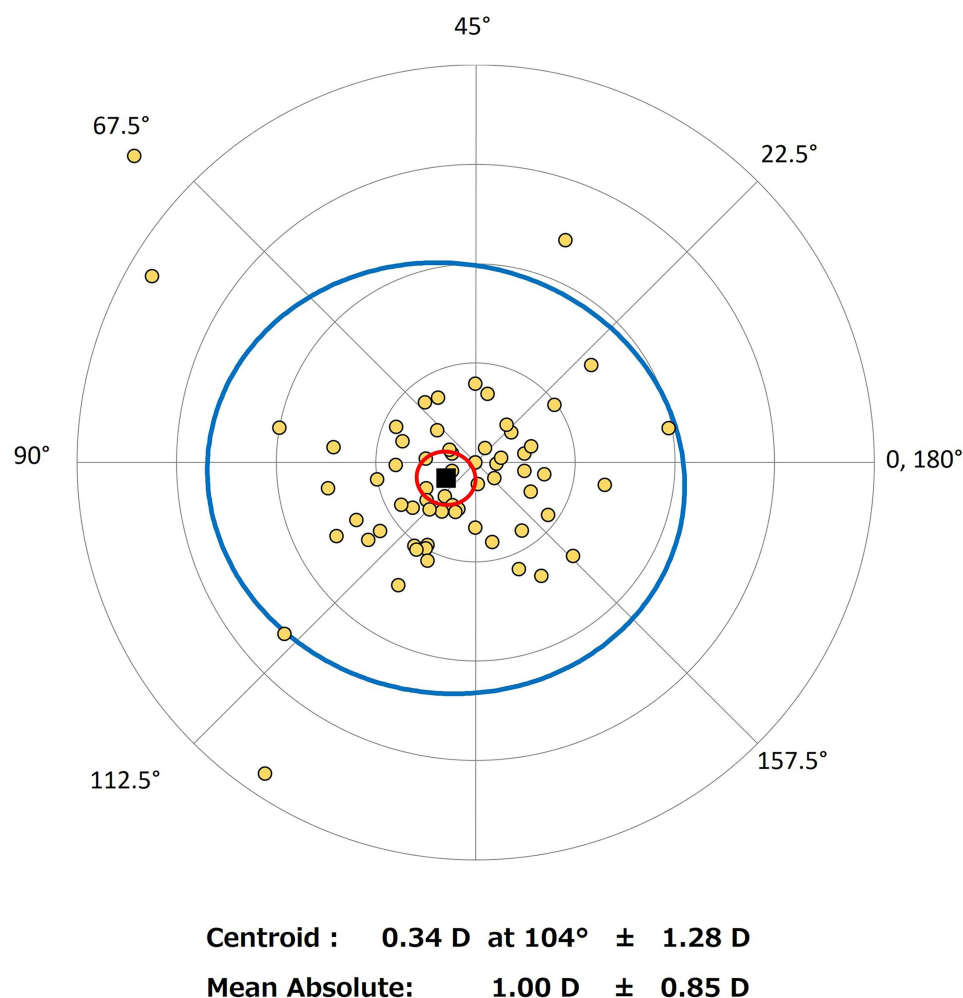
**Abbreviations:** POAG, primary open-angle glaucoma; SOAG, secondary open-angle glaucoma; PACG, primary angle-closure glaucoma; IOP, intraocular pressure; BCVA, best-corrected visual acuity; SFS, scleral flap sutures; LSL, laser suture lysis.

limbal-based). Only the magnitude, without considering direction, was used to evaluate the relationship between the magnitude of the SIA and possible related factors. The significance level was 5% (two-sided). Statistical analysis was performed using SPSS version 28.0 (IBM, Armonk, NY, USA).

## Results

Table 1 shows the clinical characteristics of the patients. Their mean age was 62.1 ± 12.7 years, and the glaucoma type included 38 primary open-angle glaucoma, 24 secondary open-angle glaucoma, and 4 primary angle-closure glaucoma. Of the 66 eyes, a triangular scleral flap was made in 37, a trapezoidal scleral flap was made in 29, a fornix-based conjunctival flap was made in 38, and a limbal-based conjunctival flap was made in 28.

The M-SIA was 1.00 ± 0.85 D, and the C-SIA was 0.34 ± 1.28 D at 104°. Figure 1 shows the distributions of SIAs as double-angle plots of individual SIAs. Although the double-angle plots showed some dissimilarities of SIA in both magnitude and direction, the direction of the centroid of SIA exhibited a trend of corneal steepening to the superior temporal location, in the direction of the scleral flap location.



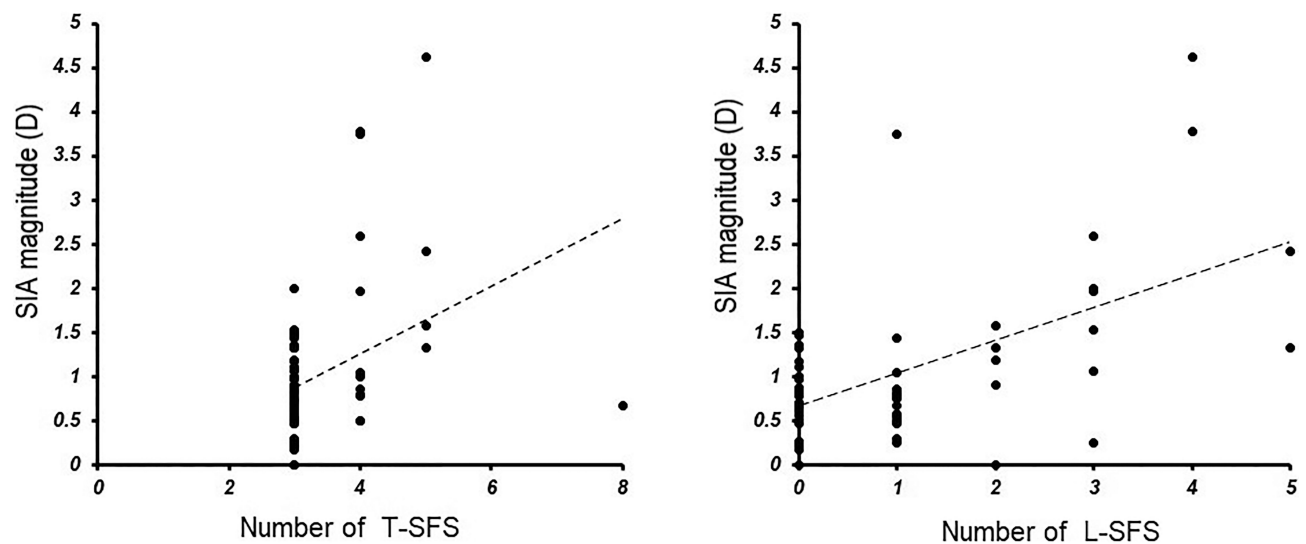
**Figure 1** Graph showing the SIA of trabeculectomy with double-angle plots. Black square and yellow dots indicate the centroid of the SIA and the SIA of each eye, respectively. Red and blue circle indicate the 95% confidence ellipses of the centroid and the dataset, respectively. Each ring indicates 1.0 D.

**Abbreviation:** SIA, surgically induced astigmatism.

There were significant correlations of SIA magnitude with the number of T-SFS (Spearman's coefficient  $r_s = 0.39$ ,  $P = 0.001$ ) and the number of L-SFS ( $r_s = 0.40$ ,  $P < 0.001$ ) (Figure 2), whereas no correlations were found with age ( $r_s = -0.096$ ,  $P = 0.44$ ), pre-operative IOP ( $r_s = 0.060$ ,  $P = 0.63$ ), 3-month postoperative IOP ( $r_s = 0.027$ ,  $P = 0.83$ ), pre-operative BCVA ( $r_s = -0.063$ ,  $P = 0.62$ ), 3-month postoperative BCVA ( $r_s = -0.023$ ,  $P = 0.85$ ), and pre-operative corneal astigmatism ( $r_s = 0.23$ ,  $P = 0.056$ ). In addition, SIA magnitude did not differ significantly by sex ( $P = 0.095$ ), shape of the scleral flap ( $P = 0.51$ ), and incision type of the conjunctival flap ( $P = 0.53$ ) (Table 2).

## Discussion

In the present study, the M-SIA after trabeculectomy was  $1.00 \pm 0.85$  D, and the C-SIA was  $0.34 \pm 1.28$  D at  $104^\circ$ . The direction of the C-SIA exhibited a trend of corneal steepening to the superior temporal location. The magnitudes of the M-SIA and the C-SIA were previously reported to be 0.65 to 2.03 D<sup>7,11,12,14–17</sup> and 0.60 to 1.01 D,<sup>12,14,15,17</sup> respectively. Compared to these previous reports, the current results were intermediate for M-SIA and slightly smaller for C-SIA. Early studies of SIA with trabeculectomy reported varying directions of SIA, probably due to the small numbers of cases or different follow-up periods and surgical techniques, but most reported a With-the-Rule (WTR) shift.<sup>4–7,13,15</sup> On the other hand, Ando et al reported an astigmatic shift in the direction of the scleral flap in a large cohort study.<sup>17</sup> In their study, the direction of the SIA exhibited a trend of corneal steepening to the superior nasal location as a result of the scleral flap creation on the superior nasal quadrant. On the other hand, in the current study, the direction of the SIA



**Figure 2** Graph showing significant correlations of the SIA magnitude with the number of T-SFS (Spearman's coefficient  $r_s = 0.39$ ,  $P = 0.001$ ) and of L-SFS ( $r_s = 0.40$ ,  $P < 0.001$ ).

**Abbreviations:** SIA, surgically induced astigmatism; T-SFS, total scleral flap sutures; L-SFS, leftover scleral flap sutures without laser suture lysis at 3 months postoperatively.

**Table 2** Effect of Clinical Factors on SIA After Trabeculectomy

Factors	P value	Spearman's Coefficient ( $r_s$ )
Number of total SFS	0.001 <sup>a</sup>	0.39 <sup>a</sup>
Number of leftover SFS without LSL	< 0.001 <sup>a</sup>	0.40 <sup>a</sup>
Age (y)	0.44 <sup>a</sup>	-0.096 <sup>a</sup>
Preoperative IOP (mmHg)	0.63 <sup>a</sup>	0.06 <sup>a</sup>
Postoperative 3 months IOP (mmHg)	0.83 <sup>a</sup>	0.027 <sup>a</sup>
Preoperative BCVA (logMAR)	0.62 <sup>a</sup>	-0.063 <sup>a</sup>
Postoperative 3 months BCVA (logMAR)	0.85 <sup>a</sup>	-0.023 <sup>a</sup>
Preoperative corneal astigmatism (dioptres)	0.056 <sup>a</sup>	0.23 <sup>a</sup>
Sex	0.095 <sup>b</sup>	
Shape of scleral flap	0.51 <sup>b</sup>	
Type of conjunctival flap	0.53 <sup>b</sup>	

**Notes:** <sup>a</sup>Spearman's rank correlation test, <sup>b</sup>Mann Whitney U-test.

**Abbreviations:** SIA, surgically induced astigmatism; SFS, scleral flap sutures; LSL, laser suture lysis; IOP, intraocular pressure; BCVA, best-corrected visual acuity.

showed a trend of corneal steepening to the superior temporal location as a result of the superior temporal scleral flap creation. These results indicate that SIA after trabeculectomy is oriented toward the scleral flap direction.

Although the mechanisms of SIA have been discussed in various ways in past studies, factors affecting corneal astigmatism have not been well investigated. Hugkulstone was the first to examine corneal astigmatism following trabeculectomy and reported a significant reduction in the vertical corneal radius (WTR change),<sup>4</sup> contrary to the expectation that the radius of corneal curvature would increase (Against-the-Rule (ATR) change) caused by the dissection of the incision as with the SIA after cataract surgery.<sup>21,22</sup> To explain the observed WTR change, he proposed that the posterior placement of the incision restricted the amount of gape, and that overlying scleral flap and

sutures provided support limiting any flattening of the vertical meridian.<sup>4</sup> In the current study, the shape of the scleral flap did not affect the SIA, supporting the notion that the effect of the scleral incision is limited, whereas the numbers of T-SFS and L-SFS were found to be significantly correlated with SIA. To the best of our knowledge, this is the first study to show a significant relationship between the scleral suture and the SIA after trabeculectomy. However, in previous studies of the SIA after trabeculectomy, no significant relationship between the suture and the SIA was reported.<sup>4,6,13,15</sup> We assume that this discrepancy might be attributed to the varied conditions of samples, as well as the small sample sizes in those studies. Indeed, the samples included bilateral eyes, different incision locations, and cases with bleb needling in some studies, and the sample size was somewhat limited in most studies. In this retrospective study, the incision location was meticulously standardized, and the unilateral analysis of the SIA was performed with a large cohort of patients undergoing trabeculectomy. Consequently, there was a significant relationship between the scleral suture and the SIA after trabeculectomy, suggesting that the scleral suture plays a key role in steepening the cornea toward the scleral flap direction in post-trabeculectomy patients.

Regarding conjunctival sutures, the SIA caused by different types of conjunctival flap was analyzed. It was expected that the fornix-based trabeculectomy would have larger SIA than the limbal-based trabeculectomy because the conjunctival sutures were closer to the cornea, but there was no significant difference. In fact, the effect of the conjunctival sutures on the SIA appeared to be limited, at least after suture removal.

There are several limitations in this study. First, this was a retrospective study. However, since the study was conducted on consecutive cases performed over a long period of time, it is considered to be quite in line with real-world practice. Second, an automated keratometer was used to evaluate corneal astigmatism, since it is most commonly used in daily practice. Therefore, the amplitude of posterior astigmatism was not evaluated in this study. To allow examination of total corneal astigmatism, evaluation of corneal astigmatism using corneal topography would be better. Third, the evaluation was made only at the 3-month postoperative time point. Though some previous reports indicated that astigmatic changes after trabeculectomy mostly occurred during the first month after surgery<sup>23</sup> and stabilized at 2–3 months postoperatively,<sup>13</sup> others indicated that changes persisted up to 1 year postoperatively;<sup>9,11</sup> thus, evaluation of longer follow-up periods should also be considered. Fourth, the effect of sutures on SIA may vary depending not only on the number of sutures, but also on the stitching technique. For example, the tension, location and direction of the suture, as well as the location and timing of the laser suture lysis may affect the SIA after trabeculectomy. These issues need further investigation.

In conclusion, this study found that trabeculectomy induced SIA in the direction of the scleral flap location, and that scleral sutures are significantly associated with SIA. The scleral suture may play a key role in steepening the cornea toward the scleral flap direction in post-trabeculectomy patients.

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## Disclosure

The authors report no conflicts of interest in this work.

## References

1. Resnikoff S, Pascolini D, Etya'ale D, et al. Global data on visual impairment in the year 2002. *Bull World Health Organ*. 2004;82:844–851.
2. Heijl A, Leske M, Bengtsson B, et al. Early manifest glaucoma trial group. Reduction of intraocular pressure and glaucoma progression: result from the early manifest glaucoma trial. *Arch Ophthalmol*. 2002;120(10):1268–1279. doi:10.1001/archophth.120.10.1268
3. Leske M, Heijl A, Hussein M, et al. Factors for glaucoma progression and the effect of treatment: the early manifest glaucoma trial. *Arch Ophthalmol*. 2003;121(1):48–56. doi:10.1001/archophth.121.1.48
4. Hugkulstone CE. Change in keratometry following trabeculectomy. *Br J Ophthalmol*. 1991;75:217–218. doi:10.1136/bjo.75.4.217
5. Cunliffe IA, Dapling RB, West J, et al. A prospective study examining the changes in factors that affect visual acuity following trabeculectomy. *Eye*. 1992;6:618–622. doi:10.1038/eye.1992.133
6. Rosen WJ, Mannis M, Brandt JD. The effect of trabeculectomy on corneal topography. *Ophthalmic Surg*. 1992;23:395–398.



7. Claridge KG, Galbraith JK, Karmel V, et al. The effect of trabeculectomy on refraction, keratometry and corneal topography. *Eye*. 1995;9:292–298. doi:10.1038/eye.1995.57
8. Dietze PJ, Oram O, Kohnen T, et al. Visual function following trabeculectomy: effect on corneal topography and contrast sensitivity. *J Glaucoma*. 1997;6:99–103. doi:10.1097/00061198-199704000-00005
9. Hong YJ, Choe CM, Lee SU, et al. The effect of mitomycin-C on postoperative corneal astigmatism in trabeculectomy and triple procedure. *Ophthalmic Surg Lasers*. 1998;29:484–489. doi:10.3928/1542-8877-19980601-09
10. Vernon SA, Zambarakji HJ, Potgieter F, et al. Topographic and keratometric astigmatism up to 1 year following small flap trabeculectomy (microtrabeculectomy). *Br J Ophthalmol*. 1999;83:779–782. doi:10.1136/bjo.83.7.779
11. Kook MS, Kim HB, Lee SU. Short-term effect of mitomycin-C augmented trabeculectomy on axial length and corneal astigmatism. *J Cataract Refract Surg*. 2001;27:518–523. doi:10.1016/S0886-3350(00)00646-5
12. Egrilmez S, Ates H, Nalcaci S, et al. Surgically induced corneal refractive change following glaucoma surgery: nonpenetrating trabecular surgeries versus trabeculectomy. *J Cataract Refract Surg*. 2004;30:1232–1239. doi:10.1016/j.jcrs.2003.11.055
13. Delbeke H, Stalmans I, Vandewalle E, et al. The effect of trabeculectomy on astigmatism. *J Glaucoma*. 2016;25:e308–e312. doi:10.1097/IJG.0000000000000236
14. Tanito M, Matsuzaki Y, Ikeda Y, et al. Comparison of surgically induced astigmatism following different glaucoma operations. *Clin Ophthalmol*. 2017;11:2113–2120. doi:10.2147/OPTH.S152612
15. Kim GA, Lee SH, Lee SY, et al. Surgically induced astigmatism following trabeculectomy. *Eye*. 2018;32:1265–1270. doi:10.1038/s41433-018-0072-9
16. Konopinska J, Byszewska A, Saeed E, et al. Phacotrabeculectomy versus phaco with implantation of the Ex-PRESS device: surgical and refractive outcomes – a randomized controlled trial. *J Clin Med*. 2021;10:424. doi:10.3390/jcm10030424
17. Ando W, Kamiya K, Kasahara M, et al. Effect of trabeculectomy on mean and centroid surgically induced astigmatism. *J Clin Med*. 2022;11:240. doi:10.3390/jcm11010240
18. Alpíns NA. A new method of analyzing vectors for change in astigmatism. *J Cataract Refract Surg*. 1993;19:524–533. doi:10.1016/S0886-3350(13)80617-7
19. Holladay JT, Moran JR, Kezirian GM. Analysis of aggregate surgically induced refractive change, prediction error, and intraocular astigmatism. *J Cataract Refract Surg*. 2001;27(1):61–79. doi:10.1016/S0886-3350(00)00796-3
20. Abulafia A, Koch DD, Holladay JT, et al. Pursuing perfection in intraocular lens calculations: IV. Rethinking astigmatism analysis for intraocular lens-based surgery: suggested terminology, analysis, and standards for outcome reports. *J Cataract Refract Surg*. 2018;44:1169–1174. doi:10.1016/j.jcrs.2018.07.027
21. Van RG, Waring GO. Changes in corneal curvature induced by sutures and incisions. *Am J Ophthalmol*. 1984;98:773–783. doi:10.1016/0002-9394(84)90697-4
22. Wishart MS, Wishart PK, Gregor ZJ. Corneal astigmatism following cataract extraction. *Br J Ophthalmol*. 1986;70:825–830. doi:10.1136/bjo.70.11.825
23. Pakravan M, Alvani A, Esfandiari H, et al. Post-trabeculectomy ocular biometric changes. *Clin Exp Optom*. 2017;100:128–132. doi:10.1111/cxo.12477

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