Corneal Curvature Change After Strabismus Surgery: An Experience from a Single Academic Center

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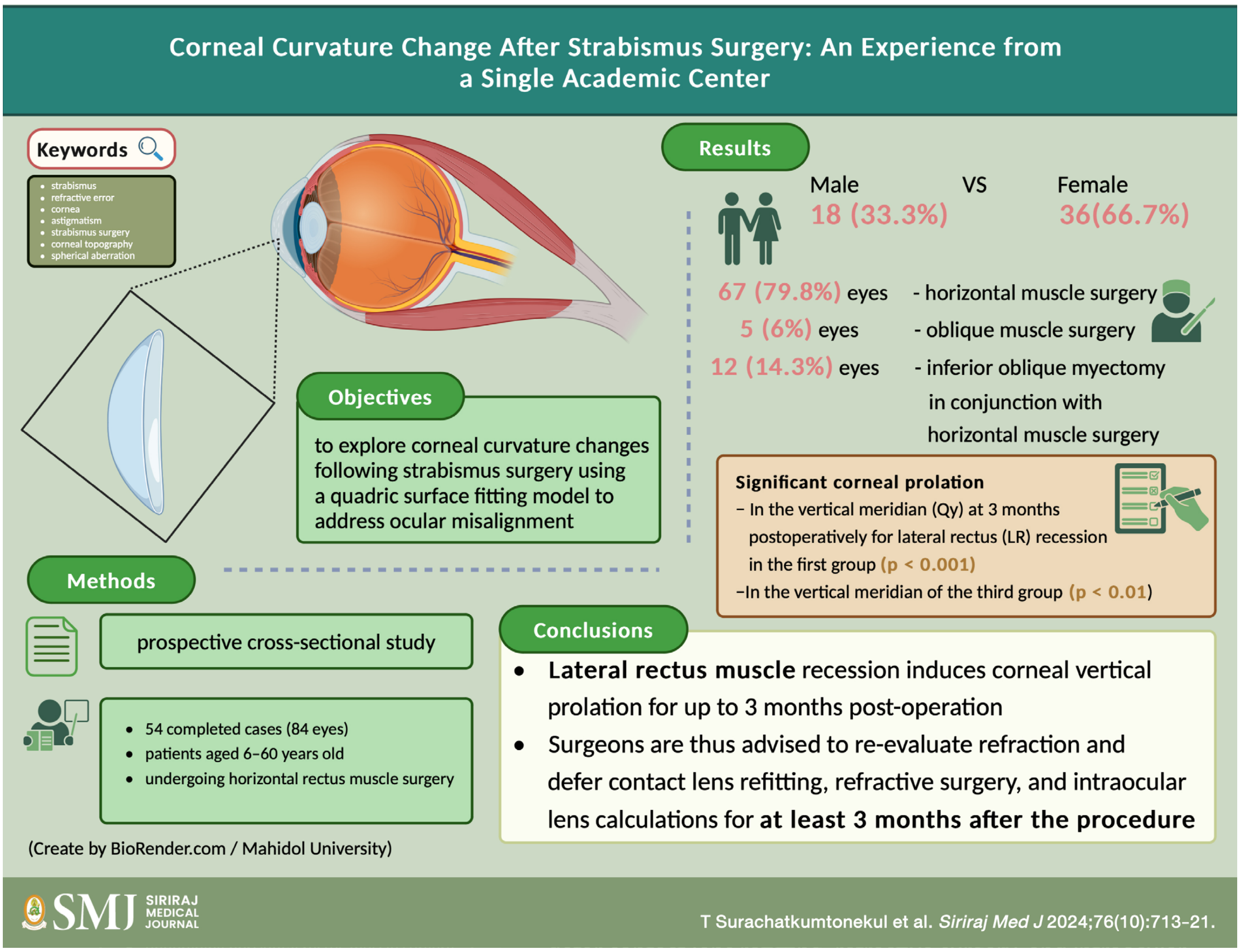

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ABSTRACT

Objective: This study aimed to explore corneal curvature changes following strabismus surgery using a quadric surface fitting model to address ocular misalignment.

Material and Methods: In this prospective cross-sectional study, 54 completed cases (84 eyes) of patients aged 6–60 years old (mean 10 years old) undergoing horizontal rectus muscle surgery were examined using placido-based keratometry with the Oculus Keratograph 5M system. Data on corneal curvature were collected one week preoperatively, and again one week, one month, and three months post-operation. Asphericity in the vertical meridian (Qy) and horizontal meridian (Qx), and surgically induced astigmatism (SIA) were calculated.

Results: The 84 eyes included were categorized into three groups: horizontal muscle surgeries, oblique muscle surgery, and combined horizontal and oblique muscle surgeries. Significant corneal prolation (steep central, flat peripheral) was revealed in the vertical meridian (Qy) at 3 months postoperatively for lateral rectus (LR) recession in the first group ($p < 0.001$), and the mean SIA was 0.45 D (95% CI: 0.35–0.56 D). A similar effect was seen in the vertical meridian of the third group ($p < 0.01$), with a mean SIA at 3 months of 0.27 D (95% CI: 0.23–0.32 D).

Conclusion: Lateral rectus muscle recession induces corneal vertical prolation for up to 3 months post-operation. Surgeons are thus advised to re-evaluate refraction and defer contact lens refitting, refractive surgery, and intraocular lens calculations for at least 3 months after the procedure.

Keywords: Strabismus; refractive error; cornea; astigmatism; strabismus surgery; corneal topography; spherical aberration (Siriraj Med J 2024; 76: 713-721)

INTRODUCTION

The cornea is a structure that has elastic properties according to the well-formed biomechanics supporting its strength. Obviously, ophthalmic procedures that involve cornea or refractive surgeries can change its shape, thickness, and curvature.[1] However, procedures performed near the cornea can affect it as well, including trabeculectomy, scleral buckling, and upper lid surgery, which were shown to have pressure effects on the cornea.[2-5] The corneal curvature is crucial in the refractive property of the eye. Besides providing two-thirds of the refractive power of the eye, it is the main factor to consider in intraocular lens calculation[6-8] for ensuring accurate contact lens fitting and a main consideration in refractive surgeries.

Although many studies have shown that the corneal curvature and refractive property are changed after strabismus surgery, the results are still varied and unpredictable.[9-15] Assessing corneal change post a procedure depends on the area of the cornea that is chosen for analysis and how the procedures are categorized.

The aim of the present study was to determine the alteration pattern of corneal curvature after strabismus surgery, including horizontal and oblique muscle surgeries. The curvatures of the horizontal and vertical meridian were analyzed separately.

MATERIALS AND METHODS

Patients and Methods

The study adhered to the principles of the Declaration of Helsinki, and the experimental protocol received approval from the Institutional Review Board at the Faculty of Medicine Siriraj Hospital (SIRB) in January 2018 (COA no. Si 021/2018). We prospectively enrolled patients aged 6 and older who underwent strabismus surgery (medial rectus, lateral rectus, and/or inferior oblique muscle surgery) between February 2018 and October 2018 at Siriraj Hospital, Bangkok, Thailand. Patients with severe corneal diseases and/or corneal scars causing irregular astigmatism were excluded from the study. We provided detailed explanations of the study protocols to participants before their study participation and obtained their informed consent before collecting data.

Ophthalmological examination

The enrolled patients underwent a comprehensive eye examination to assess their eye function, refraction, and any diseases through three methods: 1. Test of best-corrected visual acuity (BCVA); 2. Auto-refraction and keratometry using the ARK-530A system (NIDEK CO., LTD, Japan); 3. Placido-based keratometry using the Oculus Keratograph 5M system (Oculus, Inc., USA). Two trained ophthalmic technicians were assigned for the keratometry measurements. The patients' head positions were carefully checked, and they were required to maintain focus on the target during the keratometry measurements. To assess the reliability of their measurements, the ophthalmic technicians randomly did keratometry measurements of 30 eyes two times each.

We also conducted slit lamp examinations to evaluate the anterior segment of patients' eyes, searching for corneal pathologies that could affect the corneal curvature, such as corneal scars and corneal dystrophy. Pediatric and strabismus ophthalmologists examined the patients for their strabismic deviation angle and pattern.

These eye examinations were performed within 1 week before strabismus surgery and then again postoperatively at 1 week, 1 month, and 3 months. Pediatric ophthalmology staff or pediatric ophthalmology fellows, under the supervision of experienced staff, performed the strabismus surgeries. The amount of horizontal rectus muscle surgery was determined according to Marshall–Parks' surgical table.[16]

We used a conic model fitting approach to analyze corneal height data obtained with the Oculus Keratograph 5M, transforming them into Cartesian and polar coordinates. We employed a conic equation using an algorithm from Yury Petrov's ellipsoid fit method[17]:

$Ax^2 + By^2 + Cz^2 + 2Dxy + 2Exz + 2Fyz + 2Gx + 2Hy + 2Iz + J = 0,$

This equation was consistent with the one used in the study by Yue Di et al.[15] and offers certain advantages in terms of reducing localization errors and minimizing susceptibility to eye rotation during measurement.

The corneal eccentricity (e) was calculated for two axes using the following equations:

$$ex = \sqrt{1 - \frac{Rz^2}{Rx^2}}, \quad ey = \sqrt{1 - \frac{Rz^2}{Ry^2}},$$

where ex and ey represent eccentricities in the x- and y-directions, respectively, while Rx, Ry, and Rz represent the radii derived from the conic fitting model. Another term related to eccentricity is corneal asphericity (Q), which can be defined as $Q = -1e^2$.

Surgically induced astigmatism (SIA) is characterized by the differential between preoperative and postoperative refraction measurements. Villegas et al.[18] have posited that the correction of astigmatism exceeding 0.30 D is associated with a significant improvement in visual acuity. Consequently, the findings of our study underscore the clinical relevance of this value.

Statistical analysis

We calculated the required sample size to investigate the reliability of the two ophthalmic technicians for the placido-based keratometry measurements and to examine the relationship between strabismus surgery and changes in corneal refractive power after the strabismus surgery. The keratometry measurements taken by two ophthalmic technicians showed high reliability, with an ICC of 0.90. Thus, for participants whose measurements were conducted by both technicians, the average values were used to calculate changes in corneal curvature.

Therefore, using the Nquery Advisor for confidence interval [CI] method with a confidence level of 0.95, number of measurements of 2, and correlation distance limit of 0.09, we determined that a minimum sample size of 19 was needed.

To study the relationship between strabismus surgery and changes in corneal asphericity after strabismus surgery, we assumed a medium effect size of 0.15 (following Cohen's guidelines for multiple linear regression), an R^2 of 0.13, three independent variables, a significance level of 0.05, and a power of 0.80. Using Nquery Advisor, we calculated that a minimum sample size of 77 was required.

In this study, we designated corneal asphericity in the horizontal meridian as Qx and in the vertical meridian as Qy. To account for an occasional incomplete ring in the corneal topography caused by upper lid coverage, we used a central corneal diameter of 7 mm.

We utilized descriptive statistics to present the quantitative data, using the mean (SD) for normally distributed data and the median (range) for non-normally distributed data. For qualitative data, we reported numbers and percentages. To evaluate changes in corneal asphericity (Qx and Qy) before and after strabismus surgery, paired t-tests were employed to compare baseline measurements with those obtained at each follow-up time point. This within-subjects design, where the same individuals were assessed repeatedly, allows for a more sensitive analysis of changes over time by controlling for individual variability. While paired t-tests are generally not recommended for comparing multiple time points directly due to the increased risk of a Type I error, our study focused solely on comparing baseline values to follow-up measurements. This approach effectively mitigates the risk of inflated Type I error, as it avoids the multiple comparisons that can arise when comparing all possible pairs of time points.

The intra- and inter-rater reliability of the two trained ophthalmic technicians were assessed using the intraclass correlation coefficient (ICC) in a two-way mixed effects and two-way random effects model, respectively. To examine the relationship between age or the amount of recession and the ratio of Qy at 3 months postoperatively to preoperative Qy (Qy3mo/Qypre), we employed Spearman's rho correlation coefficient and scatter plots. Multiple linear regression analysis was conducted to investigate the relationship between the surgical procedures and changes in corneal spherical aberration after strabismus surgery.

Data were prepared and analyzed using MATLAB 2018a (Math Works Inc., Natick, MA, USA) and PASW Statistics for Windows, Version 18.0 (Chicago: SPSS Inc., USA). A significance level of $P < 0.05$ was considered statistically significant.[19]

RESULTS

Sixty-eight patients were initially included in the study; however, 14 patients were subsequently excluded due to loss to follow-up (n = 13) or a change in their operation plan (n = 1). Consequently, 54 patients (representing 84 eyes) were enrolled in the study. Among these participants, 36 (66.7%) cases were female, with a median age of 10 years old (ranging from 6 to 60 years old). Of the 84 eyes from the 54 included patients, 67 (79.8%) eyes underwent horizontal muscle surgery, 5 (6%) eyes underwent oblique muscle surgery, and 12 (14.3%) eyes underwent inferior oblique myectomy in conjunction with horizontal muscle surgery. The types of surgeries were categorized as shown in Table 1. The inter-rater reliability of the two ophthalmic technicians in performing keratometry measurements for both the horizontal and vertical meridians was excellent (ICC = 0.983, 95% CI: 0.965–0.991 and ICC = 0.987, 95% CI: 0.975–0.993, respectively). The intra-rater reliability of each ophthalmic technician in performing keratometry measurements for both the horizontal and vertical meridians was also excellent, with ICC values ranging from 0.989 to 0.997, as shown in Table 2.

We categorized the procedures into three groups. The first group consisted of patients who underwent horizontal muscle surgery, and their data were analyzed separately for each extraocular muscle. The second group included patients who underwent inferior oblique myectomy (IO myectomy or IO anteriorization). The third group comprised patients who underwent inferior oblique myectomy in conjunction with horizontal muscle surgery, with most of them (9 out of 12) undergoing recession.

In the first group (horizontal muscle surgery), the horizontal meridian (Qx) tended to decrease, indicating a more prolate shape (steeper center and flatter periphery) in every procedure, but this effect was transient. Similarly, the vertical meridian (Qy) of medial rectus (MR) and lateral rectus (LR) recession procedures demonstrated prolation. However, we analyzed this in each extraocular muscle surgery and found that only LR recession showed a significant change in corneal astigmatism that persisted until 3 months postoperatively. This change demonstrated statistical significance ($P < 0.01$ at 1 week, and $P < 0.001$ at 1 month and 3 months) and was correlated with the "with-the-rule" pattern of the surgically induced astigmatism (SIA) change (mean 0.45D, 95% CI: 0.35–0.56D), as shown in Fig 1.

In the subgroup analysis, for the LR recession group, there was a moderate positive relationship between the ratio of Qy at 3 months postoperatively and preoperative Qy (Qy3mo/Qypre) and age (rs = 0.531, n = 20, P = 0.016) in the children and adolescents (aged 6–18 years old), while the correlation between Qy3mo/Qypre and the amount of recession showed a low negative relationship (rs = -0.334, n = 22, P = 0.149), as shown in Fig 2.

There were no significant changes in the vertical meridian in the resection medial rectus, recession medial rectus, resection lateral rectus, or recession and resection subgroups.

In the second group, horizontal meridian (Qx) decreased significantly before returning to near the preoperative value, with no specific pattern of alteration in the vertical meridian (Table 3). Although the Qx of the third group exhibited a similar pattern to the second group, the vertical meridian (Qy) showed a statistically significant decrease at 1 and 3 months after the surgeries (p-value = 0.027 and p-value = 0.007, respectively) (Table 4); however, the amount of change was not clinically significant (mean SIA was 0.27 D, 95% CI: 0.23–0.32D).

In the vertical meridian, multiple linear regression analyses showed that only the recession procedure had a significant relationship with a change in corneal asphericity after strabismus surgery at 1 month and 3 months,

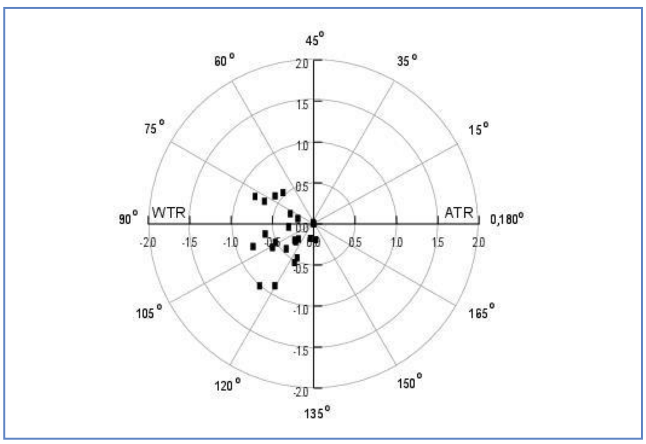

Fig 1. In the lateral rectus recession group, surgically induced astigmatism at 3 months postoperative demonstrated by double-angle vector analysis.

TABLE 1. Surgery classification and number of eyes for each operation

Procedure	Number (eyes) n = 84	Amount of muscle surgery; mm Mean (SD)
Horizontal muscle surgery (group 1)		
MR recession	19 (22.6%)	5.21 (0.56)
LR recession	22 (26.2%)	7.61 (0.67)
MR resection	8 (9.5%)	6.50 (0.50)
LR resection	9 (10.7%)	5.36 (0.48)
Resection & Recession	9 (10.7%)	
Inferior oblique (IO) myectomy (group 2)		
Inferior oblique myectomy 10 mm	5 (5.9%)	
Inferior oblique (IO) myectomy with horizontal muscle surgery (group 3)	12 (14.1%)	
With horizontal recession	9	
With horizontal resection	2	
With horizontal resection & recession	1	

Abbreviations: MR= medial rectus, LR= lateral rectus.

TABLE 2. Inter-rater and intra-rater reliability of the two ophthalmic technicians in performing the keratometry measurements

Ophthalmic technician	Asphericity Horizontal meridian (Qx) ICC	95%CI	*p*-value	Vertical meridian (Qy) ICC	95%CI	*p*-value
Technician A (n=30)	0.995*	0.980, 0.999	<0.001	0.997*	0.987, 0.999	<0.001
Technician B (n=30)	0.992*	0.968, 0.998	<0.001	0.989*	0.955, 0.997	<0.001
Technician A&B (n=38)	0.983**	0.965, 0.991	<0.001	0.987**	0.975,0.993	<0.001

* Intra-rater reliability using two-way mixed effects model, ** Inter-rater reliability using two-way random effects model.

compared with the recession procedures (P = 0.003 and P = 0.014, respectively). Meanwhile, in group 3, in the horizontal meridian, the results from the multiple linear regression analysis showed that recession, inferior oblique (IO) myectomy, and IO myectomy with horizontal muscle surgery procedures had a significant relationship with changes in corneal asphericity after strabismus surgery, compared with recession procedures only at 1 week postoperatively (P = 0.030, P = 0.033, and P = 0.014, respectively).

DISCUSSION

This study showed a significant change in corneal curvature persisted until three months after the strabismus surgery in only lateral rectus (LR) recession procedures (0.45 diopter, D) and inferior oblique myectomy with horizontal muscle surgery procedures (0.27 D), specifically in the vertical meridian (Qy) which is perpendicular to the surgical axis. The force exerted by extraocular muscles during strabismus surgery can similarly influence the cornea, leading to what is known as a coupling

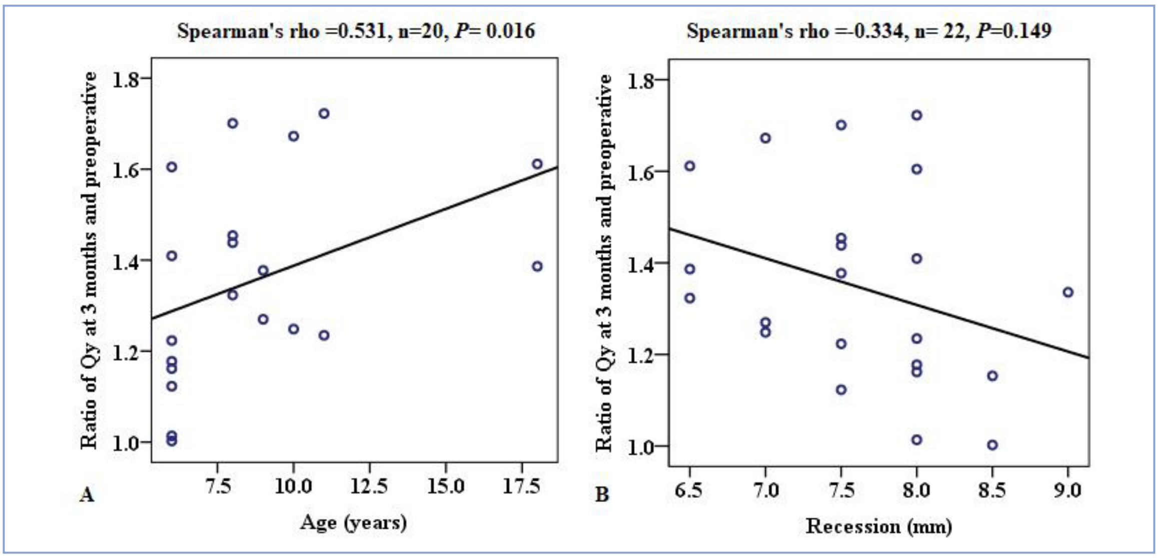

Fig 2. Spearman's rho correlation between the ratios of Qy at 3 months postoperative to preoperative (Qy_{3mo}/Qy_{pre}). A moderate positive relationship can be observed between age and Qy_{3mo}/Qy_{pre} (A) and a low negative relationship between the amount of recession and Qy_{3mo}/Qy_{pre} (B).

TABLE 3. Comparison between preoperative and 1 week, 1 month, and 3 months postoperative asphericity in the horizontal meridian (Qx)

Procedure	Asphericity in the horizontal meridian (Qx) Pre-op mean (SD)	1 week post-op mean (SD)	1 month post-op mean (SD)	3 months post-op mean (SD)
Group 1 (n=68)				
MR recession (n=19)	-0.191 (0.112)	-0.245 (0.127)	-0.196 (0.119)	-0.171 (0.078)
		***P* = 0.008**	*P* = 0.608	*P* = 0.370
LR recession (n=22)	-0.296 (0.083)	-0.318 (0.111)	-0.308 (0.100)	-0.302 (0.121)
		P = 0.132	*P* = 0.266	*P* = 0.661
MR resection (n=8)	-0.268 (0.161)	-0.297 (0.169)	-0.302 (0.176)	-0.267 (0.178)
		P = 0.547	*P* = 0.195	*P* = 1.000
LR resection (n=9)	-0.263 (0.168)	-0.279 (0.153)	-0.241 (0.132)	-0.241 (0.143)
		P = 0.133	*P* = 0.193	*P* = 0.251
R&R (n=9)	-0.250 (0.110)	-0.291 (0.110)	-0.277 (0.137)	-0.266 (0.126)
		P = 0.098	*P* = 0.250	*P* = 0.734
Group 2 (n=5)	-0.283 (0.09)	-0.363 (0.116)	-0.333 (0.090)	-0.323 (0.094)
		P = 0.063	*P* = 0.125	*P* = 0.188
Group 3 (n=12)	-0.255 (0.123)	-0.319 (0.119)	-0.289 (0.102)	-0.264 (0.108)
		***P* = 0.028**	***P* = 0.008**	*P* = 0.561

Group 1 = horizontal muscle surgery;
Group 2 = inferior oblique myectomy;
Group 3 = inferior oblique myectomy with horizontal muscle surgery
Abbreviations: R&R = resection and recession, MR = medial rectus, LR = lateral rectus.

TABLE 4. Comparison between preoperative and 1 week, 1 month, and 3 months postoperative asphericity in the vertical meridian (Qy)

Procedure	Asphericity in vertical meridian (Qy)			
	Pre-op mean (SD)	1 week post-op mean (SD)	1 month post-op mean (SD)	3 months post-op mean (SD)
Group 1 (n=68)				
MR recession (n=19)	-0.033 (0.016)	-0.040 (0.025)	-0.042 (0.019)	-0.038 (0.014)
		P = 0.282	***P* = 0.023**	*P* = 0.164
LR recession (n=22)	-0.032 (0.022)	-0.036 (0.021)	-0.040 (0.021)	-0.041 (0.023)
		***P* = 0.005**	***P* < 0.001**	***P* < 0.001**
MR resection (n=8)	-0.043 (0.031)	-0.042 (0.026)	-0.041 (0.028)	-0.039 (0.029)
		P = 0.312	*P* = 0.383	*P* = 0.039
LR resection (n=9)	-0.039 (0.021)	-0.039 (0.025)	-0.042 (0.023)	-0.043 (0.022)
		P = 0.913	*P* = 0.225	*P* = 0.102
R&R (n=9)	-0.028 (0.029)	-0.026 (0.031)	-0.027 (0.030)	-0.025 (0.029)
		P = 0.820	*P* = 1.000	*P* = 1.000
Group 2 (n=5)	-0.031 (0.018)	-0.025 (0.016)	-0.031 (0.020)	-0.027 (0.016)
		***P* = 0.011**	*P* = 0.751	*P* = 0.054
Group 3 (n=12)	-0.027 (0.020)	-0.031 (0.022)	-0.032 (0.024)	-0.034 (0.024)
		P = 0.065	***P* = 0.027**	***P* = 0.007**

Group 1 = horizontal muscle surgery;
Group 2 = inferior oblique myectomy;
Group 3 = inferior oblique myectomy with horizontal muscle surgery
Abbreviations: R&R = resection and recession, MR = medial rectus, LR = lateral rectus; R&R.

effect. In our study, the reduced force on the horizontal meridian of the cornea, due to the recession of the LR muscle, was accompanied by an increased force on the vertical meridian, primarily from the superior rectus (SR) and inferior rectus (IR) muscles. This resulted in a change in corneal curvature, with less force acting on the horizontal meridian and more on the vertical meridian. This phenomenon of corneal curvature change in the perpendicular meridian to the surgical axis can be explained by Gauss's law of elastic domes.[20,21]

Similar to many previous studies that showed a with-the-rule corneal astigmatism change following lateral rectus muscle recession procedures[9–15,22–24], our study also showed that this astigmatism change persisted until 3 months post-operation.

The change in corneal curvature in the vertical meridian in the combined horizontal muscle surgery in the IO myectomy group (0.27 D) was less pronounced than in the LR recession procedure group (0.45 D), which may have been due to a weakening effect on the vertical meridian caused by the IO myectomy.

In the IO myectomy with horizontal muscle surgery procedures group, the majority of cases involved combined horizontal muscle recession. This likely explains why the Qy value progressively became prolate, similar to what was observed in LR and MR recession. Eum SJ et al.'s study[25] showed that combined inferior oblique anterior transposition and horizontal muscle surgery resulted in transient incyclotorsion that persisted for 1 week post-operation, which differed from our study, in which it persisted for 3 months, with the difference likely because of the different operations and corneal astigmatism measurement method used.

Conversely, in the resection and recession (R&R) group, the forces from strengthening were offset by a weakening effect. In another study involving an R&R group, Schworm et al.[9] reported an increase in keratometry (K) values for the cornea adjacent to the resection and a decrease in K values for areas adjacent to the recession. Consequently, there was no significant change in asphericity in both the vertical and horizontal meridians in the R&R group. While there is less research on resection compared to recession, the available data suggest there is no significant change in corneal curvature or overall refraction.[9,14]

El Gendy HA et al.[26] found that recession had more powerful effects on corneal astigmatism compared to other operations, and that even one muscle recession had a greater effect on the cornea than multiple other muscle surgeries. These results were the same way as in our study. This corneal curvature change may explain why some poststrabismus surgery patients complained of blurred vision. In our study, the patients may have blurred vision at less than the 3 months period post-operation.

There are some limitations of our study to note, including the different number of cases in each group and the short follow-up period of only three months post-surgery. A longer period of follow-up may potentially show stronger evidence of corneal astigmatism; particularly as Al Tamini E et al.'s study[14] suggested that corneal curvature changes could continue for up to six months after surgery. Future research could consider extending the study period to a longer period post-surgery for further exploration of this phenomenon.

CONCLUSION

Only LR recession significantly affected the corneal curvature in the vertical meridian, resulting in a more prolate shape that persisted for at least three months post-surgery. Further, this was not only statistically significant but also clinically relevant, with a mean surgically induced astigmatism (SIA) of 0.45 D (95% CI: 0.35–0.56 D) in a with-the-rule pattern. As a result of these findings, we recommend giving preoperative advice about a possible refractive error change and a cautious approach to postoperative management.

Conflict of Interest

The authors declare that they have no conflicts of interest related to the publication of this research.

Author Contributions

TS: general research process, framework of the study, supervision, writing-original draft preparation, review and editing; ST: methodology, data analysis, review and editing; KS: framework of the study, resources, methodology, data collection, data analysis; PS: access to crucial research components (equipment); MS: access to crucial research components (equipment); WS: data analysis; PJ: data analysis, review and editing. All authors read and approved the final manuscript.

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