Changes in refractive error and axial length after horizontal muscle surgery for strabismus

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PURPOSE To investigate changes in refractive error following horizontal muscle surgery and to analyze the relationship between these changes and axial length.

METHODS Patients with intermittent exotropia who underwent bilateral lateral rectus recession (LR group) or unilateral lateral rectus recession with medial rectus resection (RR group) were investigated prospectively. The patients were followed for at least 3 months postoperatively; refractive error, axial length, mean corneal astigmatism, anterior chamber depth, corneal thickness, and intraocular pressure were evaluated at each examination. Postoperative changes in both groups were compared.

RESULTS A total of 64 eyes of 47 patients were included—34 eyes in the LR group and 30 eyes in the RR group. In both groups refractive error, axial length, and mean corneal astigmatism significantly increased 1 day postoperatively, although the changes in all three parameters returned to their preoperative values within 1 month of surgery and remained stable thereafter for the duration of the follow-up period. There was a negative correlation between changes in axial length and refractive error toward myopia in the 64 eyes on postoperative day 1 (partial correlation coefficient $r = -0.637$; $P < 0.001$). Changes in refractive error and axial length were significantly larger in the RR than in the LR group 1 day postoperatively ($P < 0.001$ and $P < 0.001$, resp.).

CONCLUSIONS Horizontal muscle surgery induces a transient myopic shift. This is thought to be due to axial length elongation as well as changes in corneal astigmatism. (J AAPOS 2019;23:20.e1-5)

Intermittent exotropia is one of the most common types of strabismus in South Korea, with an overall incidence of 1.1 ± 0.1%.[1] Marshall[2] first reported transient changes in refractive error and corresponding decreases in visual acuity after horizontal muscle surgery; other reports followed.[2-5] Some studies reported a myopic shift[4,6]; others, a hyperopic shift.[3] Additionally, some studies noted a shift toward with-the-rule astigmatism during postoperative period.[3,5,7,8] Although most studies described that there was no correlation between horizontal muscle surgery and long-term changes in refractive error, one study reported changes for as long as 1 year after surgery.[2]

Changes in corneal curvature[4,8] and lenticular curvature[3] have also been noted to play a role in the changes in refractive error and astigmatism. However, to our knowledge, no studies comparing the changes in axial length before and after horizontal muscle surgery for exotropia have been published previously. Axial length is one of the most important factors for determining refractive error, and the progress of myopia is related to an increase in axial length.[9] The present study aimed to compare the pre- and postoperative refractive error and to analyze the causes of the observed changes in terms of changes in axial length.

Subjects and Methods

We prospectively analyzed patients at Yeungnam University Hospital who were >5 years of age and diagnosed with intermittent exotropia from December 2016 to April 2017 and who underwent bilateral lateral rectus recession (LR group) or unilateral lateral rectus recession with medial rectus resection (RR group). This study was conducted with approval of the Yeungnam University Hospital Institutional Review Board, and all procedures adhered to the tenets of the Declaration of Helsinki. Patients were excluded axial length and refractive error could not be measured because of other combined ocular diseases (eg, corneal opacity) or they had a history of ocular surgery, including extraocular muscle surgery or concurrent vertical or oblique muscle.

In order to exclude factors that may have affected the changes in refractive error during surgery, surgeries were performed under the same conditions as far as possible. All surgeries were performed under general anesthesia by the same surgeon (MMK). Using the fornix approach, all patients underwent horizontal muscle surgery using an eyelid speculum with flanges on the blades. In this technique, using 6-0 absorbable polyglactin 910

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Table 1. Baseline characteristics of 64 eyes[a]

Characteristic	Total	LR group	RR group	*P* value
No. patients (eyes)	47 (64)	17 (34)	30 (30)	
Sex (M/F)	17/30	11/6	16/14	0.355[c]
Age at surgery, years	11.41 ± 6.77	9.47 ± 3.27	13.60 ± 8.83	0.014[b]
BCVA, logMAR	0.02 ± 0.05	0.01 ± 0.22	0.03 ± 0.75	0.162[b]
Refractive errors (SE), D	−1.73 ± 2.81	−1.78 ± 2.54	−1.68 ± 3.12	0.897[b]
Axial length, mm	24.28 ± 1.28	24.39 ± 1.21	24.16 ± 1.38	0.476[b]
Mean corneal astigmatism, D	43.05 ± 1.28	42.84 ± 1.31	43.29 ± 1.22	0.165[b]
Intraocular pressure, mm Hg	16.58 ± 2.67	17.26 ± 2.48	15.80 ± 2.71	0.027[b]
Anterior chamber depth, mm	3.68 ± 0.30	3.71 ± 0.24	3.65 ± 0.35	0.383[b]
Corneal thickness, mm	558.66 ± 45.45	554.65 ± 48.93	563.20 ± 41.51	0.457[b]

BCVA, best-corrected visual acuity; *D*, diopter; *logMAR*, logarithm of the minimum angle of resolution; *LR*, lateral rectus recession; *RR*, lateral rectus recession and medial rectus resection; *SE*, spherical equivalent.
[a]Values presented as mean ± SD.
[b]Independent *t* test.
[c]χ^2 test.

sutures with a spatulated needle, the scleral pass is directed anteriorly toward the cornea. The depth of the scleral pass is superficial; thus the needle produced a bump in the sclera. The sutures are pulled to advance the muscle, which is tied tightly in place to prevent sagging.

Refractive error, axial length, mean corneal astigmatism, anterior chamber depth, corneal thickness, and intraocular pressure (IOP) were evaluated preoperatively and at day 1, week 1, month 1, and month 3 postoperatively. The refractive error was measured using an autorefractor (Huvitz HRK-7000A, Huvitz Co Ltd, Gunpo, Gyeonggi-do, South Korea) 30 minutes after instillation of cyclopentolate 1% 3 times at 5-minute intervals, and the results were converted to spherical equivalent. Ocular axial length and anterior chamber depth were measured using the IOL master (Zeiss IOL master 500, Carl Zeiss Meditec AG, Jena, Germany). Because of a lack of cooperation from some patients due to their young age, corneal thickness and IOP were measured with noncontact specular microscopy (CellChek XL Specular Microscope, Konan Medical Inc, Irvine, CA) and noncontact tonometer (Nidek Nt-2000, Nidek Co Ltd, Aichi, Japan). The mean corneal astigmatism was defined as the average values of steep K and flat K. The K values were measured with corneal topography (Keratograph 5M, Oculus, Wetzlar, Germany).

Statistical analyses were performed using SPSS version 18.0 (SPSS Inc, Chicago, IL). Repeated-measures ANOVA was used to analyze the changes in parameters of 64 eyes after surgery, and the *P* value cutoff for significance was adjusted to <0.0125 after Bonferroni's correction as a post hoc test. Comparison between the LR and RR groups was evaluated by independent *t* test.

Results

A total of 64 eyes from 47 patients were enrolled—34 eyes of 17 patients in the LR group and 30 eyes of 30 patients in the RR group. Table 1 summarizes the baseline characteristics of all included eyes. Of the 64 eyes, 38 (59%) were from male patients; 26 (41%), from female patients. Mean age at the time of surgery was 11.41 ± 6.77 years (range, 5-48 years). At the time of surgery, LR group patients were significantly younger than those of the RR group ($P = 0.014$). There were no statistically significant differences between groups in sex, best-corrected visual acuity, spherical equivalent refractive error, axial length, mean corneal astigmatism, anterior chamber depth, and corneal thickness.

Changes in refractive error, axial length, mean corneal astigmatism, IOP, anterior chamber depth, and corneal thickness of the 64 eyes with surgery were evaluated (Figure 1). Compared to the baseline value, refractive error significantly increased toward myopia at postoperative day 1 ($P < 0.001$) and 1 week ($P < 0.001$). However, at 1 month, this myopic shift returned to preoperative values. Axial length and mean corneal astigmatism significantly increased at day 1 ($P < 0.001$ and $P < 0.001$, resp.); these statistically significant differences continued at week 1 ($P < 0.001$ and $P = 0.002$, resp.). Changes in refractive error, axial length, and mean corneal astigmatism returned to their respective preoperative values at month 1 ($P = 1.00$, $P = 1.00$ and $P = 1.00$, resp.) and were maintained over the rest of the 3-month follow-up. There were no statistically significant differences in IOP, anterior chamber depth, and corneal thickness over 3 months. Figure 2 illustrates the relationship between change in axial length and change in refractive error of the 64 eyes at postoperative day 1. We used partial correlation analysis to exclude the effect of mean corneal astigmatism on changes in refractive error and to confirm the correlation between change in refractive error and change in axial length. There was a statistically significant negative correlation (partial correlation coefficient $r = -0.637$; $P < 0.001$).

Table 2 presents the comparison of changes in refractive error, axial length, and mean corneal astigmatism, between the LR and RR groups, in which there were significant changes postoperatively. Change in refractive error and axial length were significantly larger in the RR group ($P < 0.001$) than those in the LR group ($P < 0.001$) at postoperative day 1; these statistically significant differences

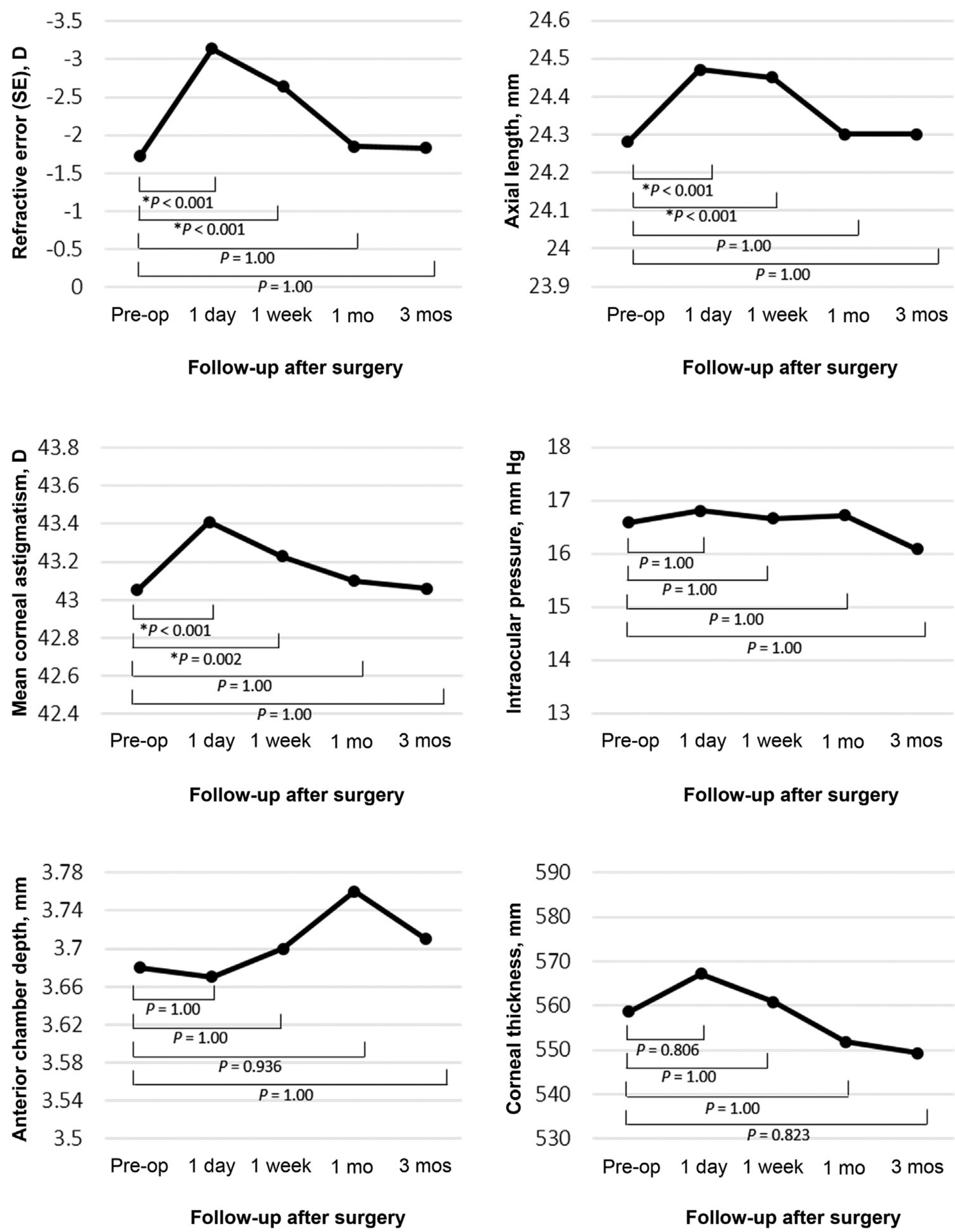

FIG 1. Changes in refractive error, axial length, mean corneal astigmatism, intraocular pressure, anterior chamber depth, and corneal thickness of 64 eyes (repeated-measures ANOVA test, *P* value cutoff for significance was adjusted <0.0125 after Bonferroni's correction as a post hoc test). *D*, diopter; *SE*, spherical equivalent.

between the groups continued at postoperative week 1 ($P = 0.001$ and $P = 0.002$, resp.). Change in mean corneal astigmatism was larger in the RR group than that in the LR group, but it was not statistically significant at postoperative day 1 ($P = 0.588$) and week 1 ($P = 0.233$).

Discussion

Our results revealed an immediate but transient postoperative myopic shift and axial length elongation following horizontal muscle surgery for intermittent exotropia. These transient changes were greater for the recession-resection procedure than for the lateral recession but occurred following both. These results suggest that morphological changes in the globe occurred after surgery.

Anatomically, corneal curvature, lens curvature, and axial length are factors that affect refractive error.[9,10] In addition, corneal thickness, anterior chamber depth, and IOP are also considered refractive components.[11,12]

Previous studies on changes in astigmatism and refractive error after horizontal muscle surgery have suggested various mechanisms, the most common being alterations of the corneal curvature owing to a decreased tension of the recessed extraocular muscle.[2,3,5,6,8,13,14] Hong and

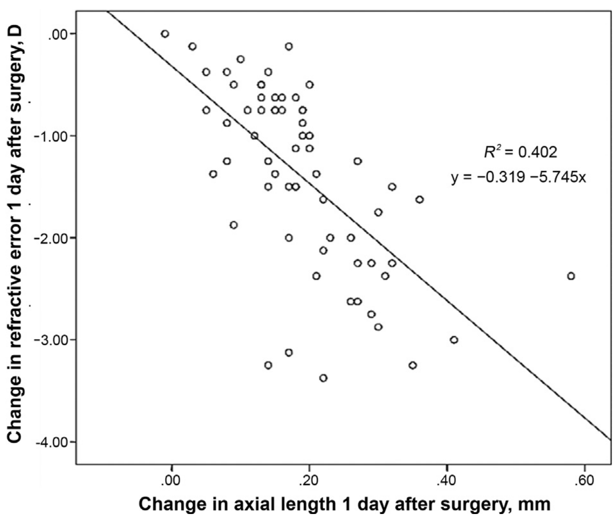

FIG 2. Relationship between the changes in axial length and the changes in refractive error of 64 eyes at postoperative day 1 (partial correlation coefficient $r = -0.637$; $P < 0.001$). *D*, diopter.

Table 2. Comparison of postoperative changes in refractive error, axial length, and mean corneal astigmatism to preoperative values between the LR group and RR group[a]

Study parameter	Time after surgery	LR group (n = 34)	RR group (n = 30)	*P* value[b]
Refractive error, D	1 day	−0.93 ± 0.70	−1.95 ± 0.78	<0.001
	1 week	−0.59 ± 0.87	−1.27 ± 0.75	0.001
	1 month	−0.14 ± 0.46	−0.10 ± 0.72	0.802
	3 months	−0.10 ± 0.67	−0.10 ± 0.53	0.996
Axial lengths, mm	1 day	0.15 ± 0.06	0.24 ± 0.11	<0.001
	1 week	0.14 ± 0.06	0.21 ± 0.11	0.002
	1 month	0.02 ± 0.05	0.01 ± 0.11	0.758
	3 months	0.02 ± 0.09	0.02 ± 0.11	0.837
Mean corneal astigmatism, D	1 day	0.32 ± 0.28	0.40 ± 0.75	0.588
	1 week	0.12 ± 0.30	0.26 ± 0.60	0.233
	1 month	0.09 ± 0.39	0.09 ± 0.41	0.902
	3 months	0.02 ± 0.27	0.08 ± 0.40	0.407

D, diopter; *LR*, lateral rectus recession; *RR*, lateral rectus recession and medial rectus resection.
[a]Values are presented as mean ± SD.
[b]Independent *t* test.

Kang[6] demonstrated that horizontal muscle surgery in children with intermittent exotropia resulted in a statistically significant shift toward myopia, and the change of muscle tension on corneal power was thought to be the major mechanism. Preslan[3] reported that segmental changes in the ciliary body circulation affect lenticular curvature, which may induce noncorneal astigmatism. Furthermore, the scleral wound healing process[13] or eyelid edema[5,8] have previously been demonstrated as causes of changes in astigmatism and refractive error after surgery.

Although axial length is one of the most important factors affecting refractive error,[9] no studies have reported on the changes in axial length after horizontal muscle surgery for exotropia. We investigated whether changes in axial length correlated with changes in refractive error. In addition, other components that could affect the refractive error were also measured to investigate whether they changed after surgery.

The present study identified statistically significant myopic shifts at the postoperative day 1 and week 1 follow-up examinations. Both axial length and mean corneal astigmatism were significantly increased, although other values were not changed before and after surgery. Moreover, it is worth noting that myopia and axial length increased after surgery and that these changes in refractive error were significantly correlated with changes in axial length.

The precise mechanisms underlying alterations in the axial length of eyes after rectus muscle surgery are unclear. We suggest two possible mechanisms. First, because rectus muscles are made up of longitudinal contractile fibers, changes in the location of the extraocular muscle insertions can alter the tension in the muscle and cause morphological changes in the globe, including the cornea and sclera. Because there was no significant change in the anterior chamber depth and corneal thickness, the increase in axial length seems to occur at the posterior part of the eye. Changes in the muscle tension are thought to affect the axial length of the globe, owing to postoperative changes in the length and attachment point of the extraocular muscles. Our second hypothesis is that mechanical factors during surgical procedures of muscle surgery may cause axial length elongation. In the process of reattaching the disinserted extraocular muscles to their new scleral position, tightly tying the scleral suture to prevent sagging of the muscle from its intended position may induce segmental indentation of the globe, which eventually can result in axial elongation. Previous published reports on the changes in axial length and corneal curvature after the encircling procedure using a silicone band for retinal detachment have suggested similar mechanisms,[15,16] although in our study only subtle segmental indentation effects of suturing would be observed in contrast to a silicone encircling band.

Changes in refractive error and axial length were significantly larger in the RR group compared to the LR group. The changes in mean corneal astigmatism was also numerically (though not significantly) larger in the RR group. This result corresponded with the results of a previous study, which reported that changes in refractive error observed with two-horizontal-rectus-muscle surgery were greater than that for one-muscle surgery.[17] Indeed, the amount of globe deformation caused by postoperative changes of insertion site and rectus muscle length is likely larger in the RR group (two-muscle surgery in one eye) than the LR group (one-muscle surgery in one eye). The significant postoperative increase in mean corneal astigmatism and axial length is consistent with previous studies showing that changes in refractive error are affected by changes in corneal curvature.[14]

Myopic shift after surgery returning to its preoperative value at postoperative month 1 parallels a previous study that reported transient myopic shift.[4] There was no significant difference in axial length at postoperative month 1, which finding supports the connection of myopic shift to elongation in axial length. However, in 10 eyes of 5 patients in the LR group and 6 eyes of 6 patients in the RR group, myopic shift did not return to preoperative values until 3 months postoperatively. This might be explained by the fact that the average age of these 11 patients was 9.63 ± 2.60 years old, which coincides with the age at which myopia increases physiologically.[18-20]

There were several limitations to our study. First, IOP and corneal thickness were measured by noncontact tonometry, which, although less accurate than contact measurement, was easier to perform in young children. Further studies in adults are required to completely exclude the influence of IOP and corneal thickness on axial length elongation. Second, the age at surgery of patients in the RR group was significantly older than that of the LR group patients. Both surgical techniques are generally performed for intermittent exotropia, and the choice of surgery depends on the expression pattern of exotropia, the amount of deviation, and the surgeon's preference.[21-23] In our study, the surgeon generally chose to perform recession-resection surgery in older patients, possibly resulting in selection bias.

McBrien and colleagues[24] have investigated alterations in scleral biomechanics that affect axial length elongation and result in myopia.[24] The present study did not investigate the possible relationship between scleral receptors and axial length. Moreover, there was no comparison with medial rectus or vertical rectus muscle recession or plication or resection. Further research on changes in refractive error after other strabismus surgeries would contribute to our understanding of morphological changes in the globe after surgery.

Literature Search

PubMed and Google Scholar were searched on September 1, 2017, without language or date restrictions, using the following terms, singly and in combination: *refractive error*, *axial length*, *corneal astigmatism*, *strabismus*, *exotropia*, *myopia*, and *horizontal muscle surgery*.

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