KJO
pISSN: 1011-8942 eISSN: 2092-9382

Korean J Ophthalmol 2016;30(6):459-467
http://dx.doi.org/10.3341/kjo.2016.30.6.459

Original Article

Comparison of Astigmatism Induced by Combined Inferior Oblique Anterior Transposition Procedure and Lateral Rectus Recession Alone

Sun Jung Eum, Bo Young Chun

Department of Ophthalmology, Kyungpook National University School of Medicine, Daegu, Korea

Purpose: The purpose of this study is to compare the magnitude and axis of astigmatism induced by a combined inferior oblique (IO) anterior transposition procedure with lateral rectus (LR) recession versus LR recession alone.

Methods: Forty-six patients were retrospectively analyzed. The subjects were divided into two groups: those having concurrent inferior oblique muscle overaction (IOOA) and intermittent exotropia (group 1, 20 patients) and those having only intermittent exotropia as a control (group 2, 26 patients). Group 1 underwent combined anterior transposition of IO with LR recession and group 2 underwent LR recession alone. Induced astigmatism was defined as the difference between preoperative and postoperative astigmatism using double-angle vector analysis. Cylinder power, axis of induced astigmatism, and spherical equivalent were analyzed at 1 week, 1 month, and 3 months after surgery.

Results: Larger changes in the axis of induced astigmatism were observed in group 1, with 4.5° incyclotorsion, than in group 2 at 1 week after surgery (axis, 84.5° vs. 91°; $p < 0.001$). However, there was no statistically significant inter-group difference thereafter. Relaxation and rapid regression in the incyclotorsion of induced astigmatism were observed over-time. Spherical equivalent significantly decreased postoperatively at 1 month in both groups, indicating a myopic shift ($p = 0.011$ for group 1 and $p = 0.019$ for group 2) but did not show significant differences at 3 months after surgery ($p = 0.107$ for group 1 and $p = 0.760$ for group 2).

Conclusions: Combined IO anterior transposition procedures caused an increased change in the axis of induced astigmatism, including temporary incyclotorsion, during the first week after surgery. However, this significant difference was not maintained thereafter. Thus, combined IO surgery with LR recession does not seem to produce a sustained astigmatic change, which can be a potential risk factor of postoperative amblyopia or diplopia compared with LR recession alone.

Key Words: Astigmatism, Exotropia, Inferior oblique muscle, Strabismus

The inferior oblique (IO) muscle acts as an excyclotorter, with secondary actions of elevation and adduction [1]. Inferior oblique muscle overaction (IOOA) is a common disorder of ocular motility [2], and surgical correction is the main treatment modality. Previous clinical studies have reported that surgical weakening of the IO muscle produces incyclorotation of the axis of astigmatism by 10° [3,4]. Refractive changes after strabismus surgery have been studied extensively, but the effect of surgery on refraction and astigmatism is controversial [5-13]. Several studies have re-

Received: February 1, 2016 *Accepted*: June 1, 2016

Corresponding Author: Bo Young Chun, MD, PhD. Department of Ophthalmology, Kyungpook National University Hospital, #130 Dongdeok-ro, Jung-gu, Daegu 41944, Korea. Tel: 82-53-420-5818, Fax: 82-53-426-6552, E-mail: byjun424@hotmail.com

ported that recession of a single rectus muscle is correlated with an increase in power in the meridian of the recessed muscle [13-15]. This effect is related to a change in corneal curvature secondary to reduction in tension of the recessed extraocular muscle transmitted via the sclera to the cornea [12,16,17].

An investigation of the relationship between muscle overaction and astigmatism is beneficial because induced astigmatism after strabismus surgery can affect patient visual acuity and may increase the potential risk of postoperative amblyopia in children. We previously demonstrated that the larger is the amount of lateral rectus (LR) recession, the greater is the cylinder power obtained postoperatively [18]. Hainsworth et al. [17] reported that the amount of muscle resected or recessed may affect the amount of corneal curvature change after strabismus surgery. In their study, comparison of the calculated corneal power change from preoperative to postoperative demonstrated a statistically significant difference between the recession procedure group and the recession-resection procedure group. Therefore, it can be presumed that there may be some difference in the degree of postoperative astigmatism according to the involved extraocular muscle. A variety of studies on the effect of strabismus surgery on refraction and astigmatism in patients with intermittent exotropia, X(T), have been reported [5-8,12]. However, there is relatively little information on the objective changes in surgically-induced astigmatism after a combined IO weakening procedure with LR recession.

Thus, we analyzed surgically-induced astigmatism in patients who underwent concurrent anterior transposition of the IO muscle and LR recession and compared the findings with those in patients who underwent LR recession only. The postoperative changes in the axis and cylindrical power of induced astigmatism were calculated using double-angle vector analysis [18-20].

Materials and Methods

A retrospective review of medical records was conducted on 322 patients who underwent strabismus surgery for X(T) and IOOA between March 2007 and June 2010. Exclusion criteria for this study were age younger than 5 years, a history of strabismus surgery, coexisting dissociated vertical deviation, corneal opacity, craniofacial anomalies, lack of cooperation during measurement for refraction, ocular misalignment or visual acuity, and follow-up duration less than 3 months.

A total of 46 patients were enrolled in this study and were divided into two groups based on the type of surgery: 20 patients (group 1) with bilateral IOOA and X(T) who underwent combined bilateral anterior transposition of the IO with bilateral LR recession, and 26 patients (group 2) with only X(T) who underwent bilateral LR recession. The following parameters were analyzed: sex, age at surgery, distant and near deviation angles, preoperative and postoperative non-cycloplegic autorefraction, calculated cylinder power and axis of induced astigmatism using double-angle vector analysis, spherical equivalent (SE), and best-corrected visual acuity (BCVA).

All patients received a comprehensive ophthalmological examination on their scheduled follow-up date. Visual acuities were measured with Snellen's chart, and values were converted to the logarithm of the minimum angle of resolution (logMAR). Deviation angles were evaluated using the alternate prism cover test, and the degree of IOOA was graded as +1 to +4 based on evaluation of ocular misalignment in nine diagnostic gaze positions. All surgeries were performed by one surgeon (BYC). Under general anesthesia, the surgeon made a limbic conjunctival incision and recessed the LR muscle. The bilateral LR recession procedure was performed according to the deviation angle of the patient. Among the various surgical techniques for IO weakening procedures, all 20 patients in group 1 underwent full anterior transposition of the IO muscle regardless of the degree of IOOA. The surgical technique of anterior transposition was as follows: after the eyeball was retracted superiorly, the conjunctiva and Tenon's capsule were incised 8 mm from the limbus in the inferotemporal direction. The IO muscle was isolated with a muscle hook, and the muscle was clipped with two mosquitos and severed with Wescott scissors. One 7-0 Vicryl double-armed suture was placed through the insertion site of the muscle and reattached to the sclera adjacent to the temporal side of the inferior rectus muscle insertion site. Refraction was measured through non-cycloplegic refraction with an auto refractometer (KR-8100; Topcon, Tokyo, Japan) at 1 week before surgery and at 1 week, 1 month, and 3 months after surgery. Three consecutive refraction readings were evaluated to reach a median value of cylinder power, cylinder axis, and SE.

Induced astigmatism was defined as the difference between postoperative and preoperative refraction [19,21]. To analyze the changes in the amount and axis of cylinder with statistical analysis, we calculated induced astigmatism using the double-angle vector analysis described by Retzlaff et al. [19] and further developed by others [20-22]. Polar values (cylinder and axis) were converted to Cartesian (x and y) values according to the method described by Holladay et al. [20] using formulas to determine the mean cylinder power and axis of induced astigmatism. On a double-angle plot, the x-axis is coincident with the axis of non-oblique (90°, 0°) astigmatism and the y-axis is coincident with the axis of oblique (45°, 135°) astigmatism [20]. The surgically-induced astigmatism vector is determined by subtracting the preoperative vector from the postoperative vector. We cited an example of subtracting cylinders using the double-angle method [18,20]. In the following formula, the postoperative vector and preoperative vector are designated as numbers 3 and 1, respectively.

Example of subtracting cylinders using the double-angle mathematical method for subtraction of refraction

Postoperative cylinder (3) - preoperative cylinder (1) = induced cylinder (2)

For example, postoperative cylinder = +1.0, axis = 4°; preoperative cylinder = +1.0, axis = 70°

Step 1: Determine the x and y components of the vectors representing the cylinders.

$x1 = cylinder1 \times \cos(2 \times axis1)$ $x1 = -0.766$

$x3 = cylinder3 \times \cos(2 \times axis3)$ $x3 = 0.990$

$y1 = cylinder1 \times \sin(2 \times axis1)$ $y1 = 0.643$

$y3 = cylinder3 \times \sin(2 \times axis3)$ $y3 = 0.139$

Step 2: Determine the induced cylinder axis (axis2).

$$Axis2 = (\arctan[(y3 - y1) / (x3 - x1)]) / 2 = \arctan(-0.504 / 1.756) / 2 = -8° = 172°$$

Step 3: Determine the induced cylinder power (cylinder power 2).

$$\text{Cylinder power 2} = [cylinder3 \times (\cos(2 \times (axis3 - axis2)))] - [cylinder1 \times (\cos(2 \times (axis1 - axis2)))]$$

$$= 1.0 \times \cos(2 \times (4 - 172)) - 1.0 \times \cos(2 \times (70 - 172))$$

$$= 0.914 + 0.914 = 1.83 \text{ D}$$

X = mean value of x, Y = mean value of y

Cylinder power of induced astigmatism $= \sqrt{X2 + Y2}$,
Axis of induced astigmatism = arctan (Y / X) / 2

The cylinder power (diopter, D) and axis (°) of the induced astigmatism were analyzed at 1 week, 1 month, and 3 months after surgery. All patients in this study underwent surgery on both eyes, although we chose only the right eyes of the patients for data analysis. The Mann-Whitney *U*-test was used for comparison of induced astigmatism, SE, and BCVA between the two groups. A paired *t*-test was used to compare changes in parameters according to postoperative time points.

Statistical analysis was performed with PAWS ver. 18.0 (SPSS Inc., Chicago, IL, USA). The results are expressed as mean ± standard deviation. Statistical significance was defined as *p*-value <0.05 for all tests.

Results

Clinical findings of patients are shown in Table 1. A total of 46 eyes of from 46 patients were included from 26 male and 20 female patients. Patients were divided into two groups: group 1 (20 eyes of 20 patients) receiving concurrent bilateral anterior transposition of the IO muscle and bilateral LR recession, and group 2 (26 eyes of 26 patients) with bilateral LR recession only. The mean age at surgery was 6.75 ± 2.22 years in group 1 and 7.42 ± 1.96 years in group 2. There were no significant differences in preoperative horizontal deviation angle at distance in the primary position or amount of LR recession between the two groups (p= 0.434 and p = 0.598, respectively). The median amount of oblique muscle overaction was +3.5 in group 1. The mean preoperative cylinder power of astigmatism was 0.72 ± 0.61 D in group 1 and 0.80 ± 0.95 D in group 2, and the axis of astigmatism was 89.0° in group 1 and 89.2° in group 2. There was no statistically significant difference in cylinder power or axis of preoperative astigmatism between the two groups (p = 0.735 and p = 0.581, respectively).

Table 2 presents the changes in induced astigmatism calculated with the double-angle mathematical method at postoperative 1 week, 1 month, and 3 months. We compared the changes in induced astigmatism not only between preoperative and postoperative times, but also between the two subgroups. At 1 week after surgery, the mean cylinder power of induced astigmatism was 0.84 ± 0.87 D and the axis of induced astigmatism was 84.5° in group 1, while those in group 2 were 0.80 ± 0.92 D and 91.0°, respectively. An incyclotorsion of 4.5° in the axis of induced astigmatism in group 1 was observed with statistically significant difference at 1 week after surgery (p <0.001). However, this incyclotorsional change rapidly returned toward its preoperative value, and there was no significant difference in the cylinder axis of induced astigmatism between preoperative and postoperative 1-month follow-up (p = 0.763). Considering the changes in induced cylinder axis between the groups, there was a statistically significant difference in the axis of induced astigmatism between group 1 and group 2 at postoperative 1 week (p = 0.043). However, there was no significant inter-group difference at 1 (p = 0.215) or 3 months (p = 0.742) postoperatively. Comparing the cylinder power between preoperative and postoperative times, there was a statistically significant difference in the cylinder power of induced astigmatism compared with the preoperative value in both groups until the 3-month follow-up (p < 0.05). Considering the changes in cylinder power between the two groups, the average cylinder power of induced astigmatism for group

Table 1. Clinical characteristics of the patients

	Group 1*	Group 2†	*p*-value
No. of patients	20	26	
Sex (male : female)	12 : 8	14 : 12	0.676‡
Age at surgery (yr)	6.75 ± 2.22	7.42 ± 1.96	0.282§
Preop deviation of X(T) at distance (PD)	27.75 ± 5.73	29.04 ± 5.29	0.434§
Amount of LR recession (mm)	7.90 ± 0.93	8.04 ± 0.83	0.598§
Preop astigmatismΠ			
Cylinder power (D)	0.72 ± 0.61	0.80 ± 0.95	0.735§
Axis (°)	89.0	89.2	0.581§

Values are presented as mean ± standard deviation.
Preop = preoperative; X(T) = exotropia; PD = prism diopter; LR = lateral rectus; D = diopter.
*Bilateral anterior transposition of the inferior oblique muscle and bilateral LR recession; †Bilateral LR recession; ‡Chi-square test; §Mann-Whitney *U*-test; ΠPreoperative astigmatism is defined as the median value of three consecutive measurements.

Table 2. Changes in induced astigmatism

Follow-up	Average value of induced cylinder*				*p*-value§
	Group 1†		Group 2‡		
	Power (D)	Axis (°)	Power (D)	Axis (°)	
POD 1 wk	0.84 ± 0.87	84.5	0.80 ± 0.92	91.0	0.043
p-valueΠ	0.002	<0.001	0.008	<0.001	
POD 1 mon	0.56 ± 0.47	89.7	0.45 ± 0.51	90.7	0.215
p-valueΠ	0.005	0.763	0.001	0.058	
POD 3 mon	0.40 ± 0.43	89.0	0.36 ± 0.33	90.2	0.742
p-valueΠ	0.026	0.125	0.002	0.068	

Values are presented as mean ± standard deviation.
D = diopter; POD = postoperative day.
*The induced cylinder power and axis were calculated using the double-angle mathematical method; †Bilateral anterior transposition of the inferior oblique muscle and bilateral lateral rectus recession; ‡Bilateral lateral rectus recession; §Comparison of changes in the axis of induced astigmatism between the two groups (Mann-Whitney *U*-test); ΠComparison of cylinder power and axis between preoperative value and the value at each follow-up visit.

1 was slightly larger than that in group 2, but there was no significant inter-group difference at any postoperative time point after 1 week ($p > 0.05$).

The values of mean preoperative and postoperative SE over time are shown in Table 3. SE significantly decreased at postoperative 1 week and 1 month in both group 1 (p = 0.001, p = 0.011, respectively) and group 2 (p = 0.002, p = 0.019, respectively), indicating a shift in the myopic direction. However, there was no significant difference at postoperative 3 months (p = 0.107 in group 1 and p = 0.760 in group 2). We also compared the SE between the groups at each follow-up date and found no significant difference (all $p > 0.05$). Comparing the overall mean change in SE between preoperative and 3 month postoperative values in the two groups, there was no statistically significant difference (-0.174 ± 0.487 in group 1, -0.073 ± 0.732 in group 2; p = 0.165).

Table 4 presents the preoperative and postoperative BCVA (logMAR) of the two groups. No statistically significant difference was found between preoperative and postoperative BCVA (logMAR) either in group 1 or group 2 (all $p > 0.05$ in both groups). Moreover, there was no inter-group difference at any follow-up visit (all $p > 0.05$).

Discussion

The changes in refractive status and visual acuity following uncomplicated strabismus surgery are generally short-lived and are customarily attributed to lid edema, use of eye drop medication, or photophobia [16]. If the astigmatic changes present without any of these factors, the true cause of changes in surgically-induced astigmatism and visual deficits must be determined. Refractive error changes after uncomplicated strabismus surgery have been documented in several studies [12,16]. Although the effect of extraocular muscle surgery on refractive and astigmatic changes is debatable [5-8], it is speculated that this effect is related to a change in corneal curvature secondary to the alterations in muscle tension transmitted via the sclera to the cornea [12,16,17]. Preslan et al. [12] previously reported a prospective study of preoperative and postoperative cycloplegic refractions in patients who had strabismus surgery, showing a statistically significant increase in with-the-rule astigmatism that persisted for at least 4 months. Our previous study [18] demonstrated that LR recession induced an increase in surgically-induced astigmatism in the with-the-rule direction. The increased magnitude of

Table 3. Mean preoperative and postoperative spherical equivalents

	Preop	POD 1 wk	*p*-value*	POD 1 mon	*p*-value*	POD 3 mon	*p*-value*
Group 1† (D)	0.07 ± 1.38	-0.61 ± 1.36	0.001	-0.22 ± 1.48	0.011	-0.10 ± 1.36	0.107
Group 2‡ (D)	-0.66 ± 1.11	-0.98 ± 1.04	0.002	-0.70 ± 0.94	0.019	-0.74 ± 0.93	0.760
p-value§	0.058	0.297		0.183		0.066	

Values are presented as mean ± standard deviation.
Preop = preoperative; POD = postoperative day; D = diopter.
*Comparison of spherical equivalents between preoperative and 1 week, between 1 week and 1 month, and between 1 month and 3 months after surgery (paired *t*-test); †Bilateral anterior transposition of the inferior oblique muscle and bilateral lateral rectus recession; ‡Bilateral lateral rectus recession; §Comparison of spherical equivalents between the two groups at each follow-up visit (Mann-Whitney *U*-test).

Table 4. Preoperative and postoperative best-corrected visual acuity values (logMAR)

	Preop	POD 1 wk	*p*-value*	POD 1 mon	*p*-value*	POD 3 mon	*p*-value*
Group 1†	0.10 ± 0.08	0.12 ± 0.10	0.085	0.11 ± 0.09	0.193	0.10 ± 0.08	0.338
Group 2‡	0.09 ± 0.07	0.10 ± 0.06	0.071	0.10 ± 0.08	0.726	0.09 ± 0.08	0.235
p-value§	0.626	0.452		0.890		0.739	

Values are presented as mean ± standard deviation.
logMAR = logarithm of the minimum angle of resolution; Preop = preoperative; POD = postoperative day.
*Comparison of best-corrected visual acuity between preoperative and 1 week, between 1 week and 1 month, and between 1 month and 3 months after surgery (paired *t*-test); †Bilateral anterior transposition of the inferior oblique muscle and bilateral lateral rectus recession; ‡Bilateral lateral rectus recession; §Comparison of best-corrected visual acuity between the two groups at each follow-up visit (Mann-Whitney *U*-test).

surgically-induced astigmatism was proportional to the amount of LR recession, and this statistically significant change was observable at the 1 week postoperative examination. However, this significant difference between the moderate- and large-recession groups was not maintained thereafter. Relaxation of astigmatism trended toward the preoperative value over time in both groups; at 1 month and 3 month follow-up, there was no statistically significant difference in the magnitude of induced astigmatism between subgroups [18].

Although the effect of strabismus surgery on refractive error has been studied extensively in previous reports [5-13], there was little information about the effect on astigmatic change after oblique muscle surgery. According to the study of Kushner [3], it was assumed that surgery of an oblique muscle was expected to produce a torsional rotation of the globe; if this is true, patients with substantial astigmatic refractive errors should be expected to show a rotation of their axis of astigmatism after undergoing a surgical weakening or tightening procedure of an oblique muscle. We agreed with Kushner's assumption; therefore, we designed our study assuming it to be true. Factors that could worsen refractive errors after oblique muscle surgery should be sought and corrected, particularly important in preverbal children who have been previously amblyopic or are at high risk for amblyopia. Therefore, we aimed to evaluate and compare the magnitude and axis of surgically-induced astigmatism by LR recession alone versus in combination with anterior transposition of the IO muscle.

In this study, the amount of surgically-induced astigmatism was analyzed and compared in patients who had undergone either combined anterior transposition of IO muscle with LR recession (group 1) or LR recession alone (group 2) during the 3-month follow-up period. At 1 week after surgery, postoperative statistically significant incyclotorsion of 4.5° in the axis of induced astigmatism in group 1 was observed compared with the preoperative value ($p < 0.001$). However, this temporary incyclotorsion rapidly returned toward the preoperative value at postoperative 1 month ($p = 0.763$) and was maintained until the 3 month follow-up ($p = 0.125$). In addition, comparing the postoperative induced cylinder axis between the two groups, there was a statistically significant difference in the axis of induced astigmatism at 1 week after surgery (84.5° in group 1 and 91.0° in group 2, $p = 0.043$). However, there was no significant inter-group difference at the postoperative 1 month ($p = 0.215$) or 3 months follow-up ($p = 0.742$).

There have been various reports on the duration of torsional effect after IO weakening surgeries [3,23]. Kushner [3] reported that weakening of the IO muscle produced a long-term 10° incyclorotation of the astigmatic axis for at least 6 months, and there was no return of the axis toward the preoperative orientation. On the contrary, Santiago et al. [23] had reported that anterior transposition of the IO muscle initially decreased objective excyclotorsion, but the effect weakened after 10 weeks. The results of our study correspond with the above studies that have reported that IO weakening procedures caused an incyclotorsion of the globe. It has been reported that postoperative refractive error stabilizes at 3 to 6 months after eye muscle surgery [3,5,12,13,23]. Therefore, we collected postoperative data at three time points (1 week, 1 month, and 3 months follow-up) to analyze the changes in refractive error. Notably, we found an unexpected difference in the recovery rates of surgically-induced incyclotorsion. In our study, the duration of a temporary incyclotorsion after anterior transposition of IO muscle combined with LR recession was relatively shorter than that in a previous study [3], and this abnormality rapidly recovered toward the preoperative value after 1 month. Furthermore, when comparing induced cylinder axes between the two groups, a statistically significant difference was observed only at postoperative 1 week. Thereafter, the axis of induced astigmatism after combined anterior transposition of the IO muscle with LR recession changed toward the axis of the control groups. We postulate the reason for this rapid regression of changes in the induced astigmatic axis to be due to compensation for cyclodeviation by the strong fusional power of torsional disparities of children. Ruttum and von Noorden [24] and von Noorden [25] reported the existence of an adaptive mechanism compensating for cyclodeviation by cyclofusion, which prevented awareness of image tilting and overcame cyclotropia based on empirical factors regarding sensory reorientation. The existence of such sensorial adaptation to torsion eradicated the effect of IO weakening surgery.

The cylinder power of induced astigmatism did not vary significantly when comparing patients with solely bilateral LR recession to those with concurrent bilateral anterior transposition of the IO muscle and bilateral LR recession. Al-Haddad et al. [26] also reported that no significant difference in the occurrence of astigmatism was observed between a horizontal strabismus group and a horizontal strabismus combined with IOOA group. They explained this result with the hypothesis that tension of the overacting IO muscle per se did not cause a sufficient mechanical advantage on the globe to produce more pronounced astigmatism in the presence of horizontal strabismus. As a result, rectus muscle weakening procedures contributed more to the postoperative change than any added effect from the IO muscle weakening surgery. Our findings correspond with the study of Al-Haddad et al. [26]. Although the two groups in our study showed comparable amounts of cylinder power of induced astigmatism after surgery, slightly higher cylinder power in group 1 was observed until the 3 month follow-up. It seemed that a two-muscle surgery per eye in group 1 (IO and LR muscle) resulted in greater changes in the location of extraocular muscle insertion than that in group 2 (LR muscle only). Thus, the combined procedure might induce a longer inflammatory change, thus influencing an increased cylinder power of induced astigmatism in group 1 [1].

For statistical data analysis, we used the double-angle vector analysis method to subtract cylinders for calculating changes in the magnitude and axis of surgically-induced astigmatism. Most previous studies reporting on changes in refractive power after strabismus surgery evaluated mean changes in astigmatism using a keratometer or corneal topography [14,15,17]. These methods can generate discrepancies when representing magnitude and axis of induced astigmatism with angular data. Otherwise, double-angle vector analysis has the benefit of accounting for the directional effect of astigmatism. Therefore, we analyzed periodic changes in astigmatism in terms of axis and cylinder power after combined anterior transposition of the IO muscle in patients who had concurrent X(T) using vector analysis of postoperative medical records.

The SE of the refraction in our study changed with a significant myopic shift at 1 week and 1 month after surgery, but it did not show significant difference between the groups at 3 months postoperative. The overall mean change in SE between preoperative and 3 months postoperative values was -0.174 ± 0.487 in group 1 and -0.073 ± 0.732 in group 2, and there was no significant difference between the two groups (p = 0.165). In our study, SE changed in agreement with previous studies of change in myopic direction [5,21]. Hong and Kang [5] reported that the SE change represented a significant myopic shift after horizontal rectus muscle surgery at the first week. Thereafter, the myopic shift persisted until 6 months postoperatively, though there was no statistically significant difference. Furthermore, the study reported that the mean change in SE after surgery showed no significant inter-group difference. The same authors reported that the myopic shift might be caused by strabismus surgery itself considering that age did not show a significant correlation with SE; the results of our study closely corresponded with the above study. However, further studies to determine the exact mechanism between strabismus surgery and SE should be performed. Furthermore, future investigation about a relationship between degree of SE and type of strabismus surgery should be evaluated.

A statistically significant difference in the cylinder power of induced astigmatism compared with the preoperative value was observed in both groups until the 3-month follow-up. Also, the cylinder axis of induced astigmatism compared with the preoperative value was significantly different at 1 week after surgery in both groups. These changes in astigmatism may induce vision changes, so we compared the visual acuity of the two groups before and after surgery. No statistically significant difference was found between preoperative and postoperative BCVA (logMAR) either in group 1 or group 2 (all $p > 0.05$ in both groups), and there was also no inter-group difference (all $p > 0.05$). Rajavi et al. [27] reported that LR recession induced significant change only in the astigmatic axis toward with-the-rule astigmatism, and not in astigmatic power or SE at 1 month or 3 months after surgery. Although the authors did not directly evaluate preoperative or postoperative visual acuity, they reported that shift of axis would not be practically notable, considering insignificant alteration in astigmatic power. Hong and Kang [5] also reported that small statistical astigmatic changes did not seem to be clinically important. In our study, cylinder power and axis of induced astigmatism showed statistically significant differences compared with the preoperative values, but these astigmatic changes did not affect vision changes in either group, in agreement with the previous studies [5,27].

Limitations of this study include analyses from retrospective design, a small number of patients, and a relatively short follow-up period. In this study, all patients who underwent combined IO weakening surgery had only anterior transposition of the IO muscle, so the differential effects of other various types of IO weakening surgeries were not studied. In addition, this study lacks measurements with subjective degrees of torsion such as the double Maddox rod test and objective degrees of torsion such as fundal photography. Kushner [3] attempted to correlate changes in the astigmatic axis with changes in subjective cyclorotation as measured with the double Maddox rod; however, he encountered some problems; he found that measurement of cyclotropia with the double Maddox rod was often not reproducible to less than 5° in the same patients. The amount of cyclotropia observed in the fixed eye seemed to vary considerably [3]. Also, patients with long-standing cyclotropia, often associated with primary oblique dysfunction, undergo a sensory reorientation of their cyclotropic eye and may not appear to have a cyclotropia on the double Maddox rod test [3,24]. However, he found that, in patients with subjective symptoms of cyclotropia, who did undergo double Maddox rod testing, the change in subjective cyclotropia postoperatively was similar to the change in astigmatic axis [3]. Therefore, we also did not measure subjective cyclotropia by double Maddox rod; further, most of our patients were very young and were not able to understand the test. Future studies with more patients and a longer follow-up with different surgery types of horizontal and cyclovertical strabismus are highly recommended to confirm true statistically significant difference.

In conclusion, combined IO anterior transposition procedure with LR recession caused more changes in the axis of induced astigmatism than did LR recession alone during the first week after surgery. However, this incyclotorsion was rapidly restored toward the preoperative value and was maintained during postoperative follow-up, with no significant inter-group difference. Our results suggest that combined IO anterior transposition procedure with LR recession does not produce sustained astigmatic changes compared with LR recession alone, and these temporary changes may not interfere with the vision of patients through a longer postoperative period.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

References

1. von Noorden GK. Clinical observations in cyclodeviations. *Ophthalmology* 1979;86:1451-61.
2. Parks MM. The overacting inferior oblique muscle. *Am J Ophthalmol* 1974;77:787-97.
3. Kushner BJ. The effect of oblique muscle surgery on the axis of astigmatism. *J Pediatr Ophthalmol Strabismus* 1986;23:277-80.
4. Sim JH, Lee SY. The effect of inferior oblique weakening procedures on the correction of ocular torsion. *J Korean Ophthalmol Soc* 2005;46:1020-6.
5. Hong SW, Kang NY. Astigmatic changes after horizontal rectus muscle surgery in intermittent exotropia. *Korean J Ophthalmol* 2012;26:438-45.
6. Noh JH, Park KH, Lee JY, et al. Changes in refractive error and anterior segment parameters after isolated lateral rectus muscle recession. *J AAPOS* 2013;17:291-5.
7. Emre S, Cankaya C, Demirel S, Doganay S. Comparison of preoperative and postoperative anterior segment measurements with Pentacam in horizontal muscle surgery. *Eur J Ophthalmol* 2008;18:7-12.
8. Mun GH, Heo H, Park SW, Park YG. The changes of corneal astigmatism and refraction after horizontal rectus muscle surgery in intermittent exotropia. *J Korean Ophthalmol Soc* 2010;51:581-7.
9. Snir M, Nissenkorn I, Buckman G, et al. Postoperative refractive changes in children with congenital esotropia: a preliminary study. *Ophthalmic Surg* 1989;20:57-62.
10. Marshall D. Changes in refraction following operation for strabismus. *Arch Ophthalmol* 1936;15:1020-31.
11. Dottan SA, Hoffman P, Oliver MD. Astigmatism after strabismus surgery. *Ophthalmic Surg Lasers Imaging Retina* 1998;19:128-9.
12. Preslan MW, Cioffi G, Min YI. Refractive error changes following strabismus surgery. *J Pediatr Ophthalmol Strabismus* 1992;29:300-4.
13. Killer HE, Bahler A. Significant immediate and long-term reduction of astigmatism after lateral rectus recession in divergent Duane's syndrome. *Ophthalmologica* 1999;213:209-10.
14. Nardi M, Rizzo S, Pellegrini G, Lepri A. Effects of strabismus surgery on corneal topography. *J Pediatr Ophthalmol Strabismus* 1997;34:244-6.
15. Kwitko S, Feldon S, McDonnell PJ. Corneal topographic changes following strabismus surgery in Grave's disease. *Cornea* 1992;11:36-40.

16. Thompson WE, Reinecke RD. The changes in refractive status following routine strabismus surgery. *J Pediatr Ophthalmol Strabismus* 1980;17:372-4.
17. Hainsworth DP, Bierly JR, Schmeisser ET, Baker RS. Corneal topographic changes after extraocular muscle surgery. *J AAPOS* 1999;3:80-6.
18. Chun BY, Kim HK, Kwon JY. Comparison of magnitude of astigmatism induced by lateral rectus recession. *Optom Vis Sci* 2010;87:61-5.
19. Retzlaff J, Paden PY, Ferrell L. Vector analysis of astigmatism: adding and subtracting spherocylinders. *J Cataract Refract Surg* 1993;19:393-8.
20. Holladay JT, Moran JR, Kezirian GM. Analysis of aggregate surgically induced refractive change, prediction error, and intraocular astigmatism. *J Cataract Refract Surg* 2001;27:61-79.
21. Bagheri A, Farahi A, Guyton DL. Astigmatism induced by simultaneous recession of both horizontal rectus muscles. *J AAPOS* 2003;7:42-6.
22. Bartier M, Putteman A. Changes in astigmatism following surgery for strabismus. *Bull Soc Belge Ophtalmol* 1988;229:87-96.
23. Santiago AP, Isenberg SJ, Apt L, Roh YB. The effect of anterior transposition of the inferior oblique muscle on ocular torsion. *J AAPOS* 1997;1:191-6.
24. Ruttum M, von Noorden GK. Adaptation to tilting of the visual environment in cyclotropia. *Am J Ophthalmol* 1983;96:229-37.
25. von Noorden GK. Clinical and theoretical aspects of cyclotropia. *J Pediatr Ophthalmol Strabismus* 1984;21:126-32.
26. Al-Haddad C, Antonios R, Khatib L, et al. Is inferior oblique overaction associated with astigmatism? *J Pediatr Ophthalmol Strabismus* 2015;52:288-93.
27. Rajavi Z, Rabei HM, Ramezani A, et al. Refractive effect of the horizontal rectus muscle recession. *Int Ophthalmol* 2008;28:83-8.