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Original Article

Formulas to Estimate Appropriate Surgical Amounts of Unilateral Recession-Resection in Intermittent Exotropia with Distance-Near Disparity

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The purpose of this study was to derive new formulas to provide an optimal surgical procedure and optimal amount of recession-resection (RR) surgery in intermittent exotropia (IXT) with a disparity in angle of deviation depending on the fixation distance. The records of 117 consecutive patients with IXT who underwent RR surgery between March 2008 and December 2011 at Okayama University Hospital were retrospectively examined. Multivariable linear regression analysis was performed using the observed corrective angle of deviation at distance or near fixation as the dependent variable, and amounts of lateral rectus muscle (LR) recession (mm) and medial rectus muscle (MR) resection, and age at surgery (years) as independent variables. Two simultaneous formulas were derived: corrective angle of deviation at distance fixation (°) = 1.8 × recession (mm) + 1.6 × resection (mm) + 0.15 × age (years) − 6.6, and corrective angle at near fixation (°) = 1.5 × recession (mm) + 1.7 × resection (mm) + 0.18 × age (years) − 3.8. Comparisons of coefficient values of the formulas between distance and near fixation revealed that LR recession was more affected by the corrective angle in distance than near fixation. MR resection was more affected at near than distance fixation. We found that our new formulas estimated the appropriate amount of unilateral RR surgery.

Key words: surgical amount, intermittent exotropia, recession and resection procedure, strabismus surgery, recurrent exotropia

Surgical procedures and amount of surgery for patients with intermittent exotropia (IXT) were reported previously [1-3]. However, the current reports in young patients over the first 4 postoperative years showed insufficiency that undercorrected more than 10 prism diopters (PD) in 68.5% of all subjects after unilateral recession-resection (RR) surgery, and overcorrected more than 5 PD in 4.1% of the subjects [4]. Lee *et al.* also showed a success rate, defined as exodeviation ≤ 10 PD and esodeviation ≤ 5 PD, in 59.6% of cases at 1 year after symmetric (bilateral lateral rectus recession) and asymmetric (RR) surgery [5]. Some reports showed higher success rates and/or shorter follow-up periods to avoid postoperative exodrift [6-8]. At present, therefore, the surgical results cannot be predicted adequately, and the success rate must be improved.

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Historically, the amounts (mm) of surgical recession of the lateral rectus muscle (LR) and/or resection of the medial rectus muscle (MR) in patients with exotropia have been determined by a simple first-degree equation in which ocular deviation (PD or angle degree) was assigned as the independent variable.

At Okayama University Hospital, the amount of surgery is selected as the smallest angle of exodeviation at distance fixation, or near fixation, by the prism adaptation test (PAT), 5 PD is corrected per 1 mm of RR surgery respectively [9]. In cases that have a preoperative angle of deviation that differed between the distance and near fixation as convergence insufficiency-type, divergence excess-type, or basic with small distance-near disparity-type IXT, it would be ideal to have a corrective surgical method. The ideal method would provide satisfactory ocular alignment and binocular function at both distance and near fixation. Such a method is not currently available.

Similarly, the appropriate amounts of unilateral RR surgery in patients in whom ocular deviations differ between distance and near fixation remain undeveloped. In such cases, the amounts of recession and/or resection may be increased or decreased based on clinician experience.

RR surgery is usually selected for convergence insufficiency-type IXT, and bilateral LR recession (BLR) for divergence excess-type IXT [10-12]. In Japan, RR surgery is selected [13], but in other countries, BLR for basic-type IXT with no difference in deviation > 10-15 PD between distance and near fixation is used. Therefore, a consensus on the best procedure for basic-type IXT has not been obtained [2]. An evaluation of the validity of selected procedures, the appropriate surgery amount, and the validity of a simple first-degree equation for IXT treatment are necessary.

The aims of the current study were to evaluate new formulas for estimation of the appropriate amount of RR for IXT with consideration of patient age and ocular deviation at distance and near fixation. The validity of two tables used to determine the surgical amount was evaluated, along with the reasonable amount of RR for distance-near disparity in the angle of deviation [1, 9].

Methods

The records of a series of 117 consecutive patients with IXT, who underwent unilateral RR surgery between March 2008 and December 2011 at Okayama University Hospital, were examined retrospectively. Patients were excluded from the analysis if they had preoperative vertical deviation of > 5 PD at distance or near fixation, infantile exotropia, amblyopia, high AC/A, any history of previous strabismus surgery, any history of surgery with vertical transposition to correct an A and V pattern [14, 15], or any history of surgery using the adjustable suture method, if they had dropped out of postoperative follow-up within 9 months, if informed consent could not be obtained, or if there was a history of other disease causing ocular deviation [for example, thyroid ophthalmopathy, myasthenia gravis, internuclear ophthalmoplegia, high grade (pathologic) myopia [16], paretic strabismus, sensory strabismus, or other neurologic disorders] The subjects' details are described in Table 1.

The extent of preoperative angle of exodeviation at

Table 1 Subject summaries

Age at surgery (Mean ± SD) (range):	20 ± 19 years (5–79)
Male/Female (rate):	55 (47%)/62 (53%)
Right/Left eye operated (rate):	52 (44%)/65 (56%)
LR recession (Mean±SD) (range):	6.6 ± 1.3 mm (4.0–9.0)
MR resection (Mean±SD) (range):	6.1 ± 2.1 mm (0.0–9.0)
The patients number of in which	
LR recession was equal to MR resection (rate):	103 (88%)
LR recession was different from MR resection (rate):	6 (5%)
LR recession only (rate):	8 (7%)
Preoperative angle of exodeviation at 5 m (Mean ± SD) (range):	19.5 ± 7.1° (6.9–47.0)
Preoperative angle of exodeviation at 0.3 m (Mean ± SD) (range):	22.9 ± 8.8° (7.4–57.6)
Follow-up period (Mean ± SD) (range):	563 ± 219 days (278–1153)
Observed corrective angle of deviation at 5 m (Mean ± SD) (range):	15.1 ± 7.6° (2.1–43.2)
Observed corrective angle of deviation at 0.3 m (Mean ± SD) (range):	17.2 ± 8.6° (−0.9–48.9)

SD, Standard deviation; LR, lateral rectus muscle; MR, medial rectus muscle.

distant fixation was recorded in each subject by means of the PAT, using the Fresnel Press-On Prism (Health Care Specialties Division/3M; St. Paul, MN, USA), which was attached to a lens of glasses for the nondominant eye to neutralize the angle of deviation. The PD was adjusted according to responses to deviation as determined by the prism and cover test (PCT), and the test was repeated at 20-minute intervals until no additional prisms were required to neutralize the distance deviation [9]. Preoperatively, the hole-in-the-card test was performed to determine the dominant eye. The eye used to view the target through the hole was defined as the dominant eye. Surgery was performed on the nondominant eye. The amount of surgery was based on the smallest angle of deviation at distance or near fixation. PCT for the angle of deviation was administered after surgery. The postoperative angle of deviation was measured for more than 9 months after surgery, in order to ensure the stability of postoperative exodrift [18]. Differences in the angle of deviation at distance or near fixation between the preoperative and last postoperative examination were defined as the observed corrective angle of deviation at distance or at near fixation.

Each corrective angle at distance or at near fixation was defined as the dependent variable, and the amounts of LR recession, MR resection, and age at surgery were defined as the independent variables. In the case of LR recession only, the amount of MR resection was equal to zero. The coefficient values of a, b, c, and p in formula (1) below, and of e, f, g, and q in formula (2) below, were determined from the relationships between the variables in each group using multivariable linear regression analysis by a direct entry method with IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA).

$$\begin{cases} d = ax_1 + bx_2 + cx_3 + p \cdots (1) \\ n = ex_1 + fx_2 + gx_3 + q \cdots (2) \end{cases}$$

Here, d is the corrective angle at distance fixation (°), n is the corrective angle at near fixation (°), x_1 is recession of LR (mm), x_2 is resection of MR (mm), and x_3 is the patient age at the time of surgery (years).

Next, the validity of 2 tables used to determine the surgical amounts, the Parks modified table and a table in the style of Okayama University Hospital [1,9], and the reasonable amounts of RR for distant-near disparity in the angle of deviation were evaluated.

Results

The results of multivariable linear regression analysis for corrective angles at distance and at near fixation are shown in Tables 2 and 3.

The formulas of (1)' and (2)' with substitution of the coefficients described above were as follows.

$$\begin{cases} \mathrm{d} = 1.8x_1 + 1.6x_2 + 0.15x_3 - 10.0 \cdots (1)' \\ \mathrm{n} = 1.5x_1 + 1.7x_2 + 0.18x_3 - 7.2 \cdots (2)' \end{cases}$$

The values of x_1 (*recession of LR*), x_2 (*resection of MR*), and x_3 (*patient age at time of surgery*) were inserted into formulas (1)' and (2)', and the corrective angles of deviation at distance and near fixation were calculated. The difference between the observed and calculated corrective angle by formulas (1)' and (2)' with the substituted parameters from actual performed surgery are shown in Fig. 1.

If the calculated corrective angles of formulas (1)' and (2)' were the preoperative angles of deviations at distance and near fixation, then the solutions of x_1 (*recession of LR*) and x_2 (*resection of MR*) to a system of

Table 2 The results of multivariable linear regression analysis for corrective angle at distance fixation

Coefficient of determination		0.57
P value in analysis of variance		0.00
Parameters	Coefficients	*p* value
Age	0.15	0.00
LR recession	1.8	0.00
MR resection	1.6	0.00
Constant	−10.0	0.00

LR, Lateral rectus muscle; MR, medial rectus muscle.
*Significance p value <0.05

Table 3 The results of multivariable linear regression analysis for corrective angle at near fixation

Coefficient of determination		0.49
P value in analysis of variance		0.00
Parameters	Coefficients	*p* value
Age	0.18	0.00
LR recession	1.5	0.00
MR resection	1.7	0.00
Constant	−7.2	0.02

LR, Lateral rectus muscle; MR, medial rectus muscle.
*Significance p value <0.05

equations would be found. The results of surgery, using these equations, can be obtained as observed corrective angles of deviation. Therefore the histograms represented the postoperative angles of deviation targeting orthophoria, and half of the subjects were overcorrected.

Orthophoria or small angle of exodeviation as a result of surgery in IXT, however, was preferable. A postoperative angle of deviation of less than 15 PD exodeviation (undercorrection) to less than 4 PD esodeviation (overcorrection) was assumed successful in terms of patient satisfaction [19,20]. Central values in this range were 6 PD of undercorrection, if surgery was performed with a target of 6 PD exodeviation. The histogram of postoperative deviation would normally be distributed around 6 PD exodeviation at the center for the best success rate. Correction formulas (1)" and (2)" were recalculated by subtracting 6 PD (3.4°) from formulas (1)' and (2)'. These formulas were considered most suitable for the RR surgery.

$$\begin{cases} d = 1.8x_1 + 1.6x_2 + 0.15x_3 - 6.6 \cdots (1)" \\ n = 1.5x_1 + 1.7x_2 + 0.18x_3 - 3.8 \cdots (2)" \end{cases}$$

The success range (< 4 PD esodeviation and 15 PD exodeviation) was therefore 10.8°. The rates of postoperative deviation were in the range of 0 ± 5.4°(range, 10.8°) as calculated using the histogram of postoperative angle of deviation centered at zero, and using formulas (1)' and (2)'. The presumed success rate at distance fixation was 72% and SD was 5.0°; at near fixation the presumed success rate was 62% and SD was 6.2°. If the target was 6 PD exodeviation, then the presumed success rates of correction formulas (1)" and (2)" were the same.

By substituting 3 values of d (preoperative angle of exodeviation at distance fixation), n (preoperative angle of exodeviation at near fixation), and age at time of surgery into the formulas of (1)" and (2)", the solutions of the x_1 (*recession of LR* (mm)) and x_2 (*resection of MR* (mm)) coefficients could be found. If a solution was negative (minus sign) it could not be used for clinical surgery. In this case, the solution was adjusted until not less than zero, even with the possibility of undercorrection of postoperative angle of deviation at either distance or near fixation. This method can be applied in a clinical setting. But in this case the success rates may be less than optimal.

Surgical amounts of RR surgery from the Parks' modified surgical table [1] and from the Okayama University Hospital's surgical table [9] were used in for-

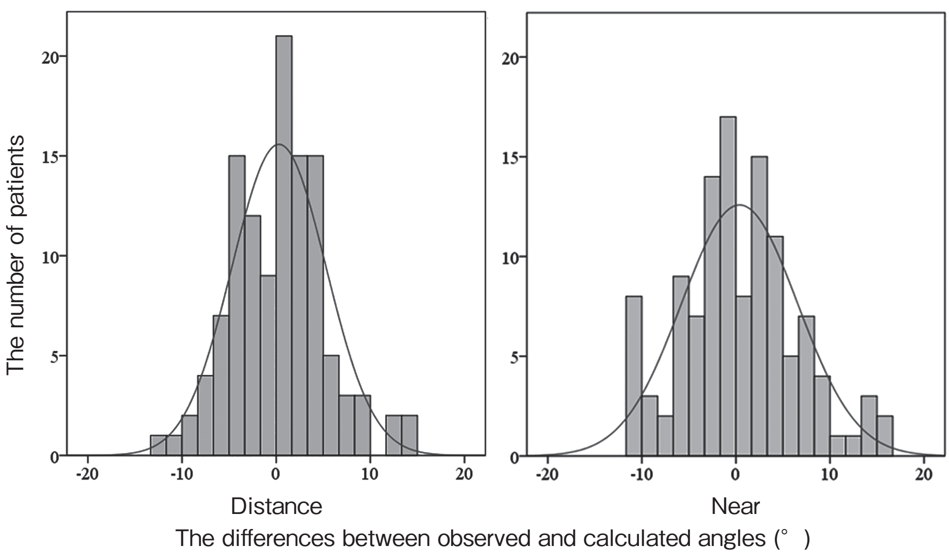

Fig. 1 Differences between observed and calculated angles. The difference between the observed corrected angle and the one calculated by formulas (1)' and (2)' substituting the surgical amount of recession/resection and age is expressed as a normal distribution. The mean (SD) of these differences were 0.3 (5.0)° at distance and 0.4 (6. 2)° at near fixation. The Shapiro-Wilk Test was used to assess data for normality. *P* values were 0.279 for distance and 0.142 for near. The alpha level was 0.05, and therefore the null hypothesis that the data were normally distributed was not rejected, and the differences in corrective angles at distance and at near fixation were considered normal. Histograms of these differences were normally distributed around zero at center.

mulas (1)” and (2)”, and the calculated corrective angles in each table were obtained (Table 4). Comparisons of the corrective angle calculated from our formulas with the corrective angle calculated for treatment of the preoperative angle of deviation in each table revealed that the calculated corrective angles were larger at near than at distance fixation, and that the modified Parks’ table tended to undercorrect for treatment of the preoperative angle of deviation for patients aged 5 years. Conversely, calculated corrective angles for adults were more overcorrective for treatment of larger preoperative angles of deviation when using the Okayama University Hospital’s table.

A histogram of age distribution for the 4 age groups is shown in Fig. 2. The number of teenagers was the largest and the number of adults was small because it was difficult for adults to visit the hospital for long periods of time due to their work.

Discussion

Formulas (1)” and (2)” were developed to evaluate

Table 4 Comparisons between surgical tables and calculated corrective angles of deviations for 5, 20 and 50 years.

A. Modefied Parks (Kenneth W. Write)

Preoperative angle (PD)	Amount (mm)		Corrective angle (PD) [ ](°)					
			5 years		20 years		50 years	
	Recession	Resection	Distance	Near	Distance	Near	Distance	Near
15	4	3	11 [6]	14 [8]	15 [8]	19 [11]	23 [13]	29 [16]
20	5	4	17 [10]	20 [11]	21 [12]	25 [14]	29 [16]	35 [20]
25	6	4.5	22 [12]	24 [14]	26 [14]	30 [16]	34 [19]	40 [22]
30	6.5	5	25 [14]	27 [15]	29 [16]	33 [18]	38 [21]	43 [23]
35	7	5.5	28 [16]	30 [17]	32 [18]	36 [20]	41 [22]	47 [25]
40	7.5	6	31 [17]	34 [19]	35 [20]	39 [21]	45 [24]	50 [27]
50	8	6.5	34 [19]	37 [20]	39 [21]	42 [23]	48 [26]	54 [28]

B. Okayama University Hospital

Preoperative angle (PD)	Amount (mm)		Corrective angle (PD) [ ](°)					
			5 years		20 years		50 years	
	Recession	Resection	Distance	Near	Distance	Near	Distance	Near
20	4	4	14 [8]	17 [10]	18 [10]	22 [13]	26 [15]	32 [18]
25	5	5	20 [11]	23 [13]	24 [13]	28 [16]	32 [18]	39 [21]
30	6	6	26 [15]	29 [16]	30 [17]	34 [19]	39 [21]	45 [24]
35	7	7	32 [18]	35 [20]	37 [20]	41 [22]	46 [25]	52 [28]
40	8	8	39 [21]	42 [23]	44 [24]	47 [25]	53 [28]	60 [31]
45	9	9	46 [25]	49 [26]	51 [27]	55 [29]	61 [32]	67 [34]
50	10	10	54 [28]	56 [29]	59 [30]	62 [32]	70 [35]	76 [37]

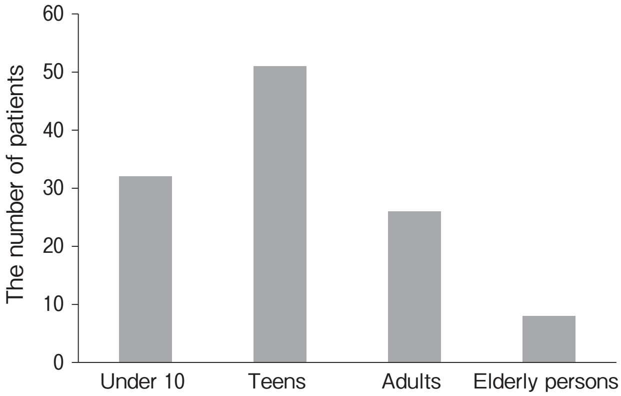

Fig. 2 Histogram of age distribution for the 4 age groups. The 4 age groups were under 10 (<10 years), teens (10-19 years), adults (20-64 years), and elderly persons (65 years or more).

the optimal surgical recession/resection amounts in IXT with near distance disparity in angle of deviation, and corrective angles at distance and at near fixation, when compared using the two tables. By using these formulas, we found that a more optimized surgical amount of recession of LR and resection of MR in the RR surgery could be estimated for optimal clinical treatment. Comparing coefficients x_1 and x_2 between formulas (1)" and (2)" for relationships between the corrective angle and surgical amounts of LR recession and MR resection, LR recession showed more influence on the corrective angle at distance than at near fixation, while MR resection showed more influence on near than distance fixation.

Choi *et al.* reported that changes from preoperative to postoperative mean exodeviation at distance and at near fixation were from 22.5 PD to 9.1 PD, and 33.8 PD to 13.6 PD, respectively, in patients with convergence insufficiency-type exotropia who underwent the RR surgery. Changes from preoperative to postoperative mean near distance disparity decreased from 11.3 PD to 4.6 PD [10]. Yang *et al.* also reported that good success rates were obtained in patients with convergence insufficiency-type exotropia who had preoperative near distance disparity of > 10 PD after occlusion test and undergoing the RR procedure [11]. They recommended the RR procedure for patients with convergence insufficiency-type. In our results, the RR surgery was better for convergence insufficiency-type than BLR because MR resection was more effective to correct the angle of deviation at near than at distance fixation. Furthermore, calculated corrective angles from both the Parks' modified table [1] and our table [9] indicated that they were more effective at near than at distance fixation. The RR surgery was recommended for convergence insufficiency-type IXT. Kushner recommended bilateral LR recession for divergence excess-type IXT [12]. We concurred with this recommendation because LR recession was more effective to correct the angle of deviation at distance than at near fixation.

Some reports found an association between the corrective angle and treatment of the preoperative angle of deviation and the surgical effects [3,13]. The studies indicated that the larger the amount of recession of LR and resection of MR, the larger the surgical effect in corrective angle per millimeter. Therefore, the smaller the surgical amount, the less was the effect. In our analyses, the intercepts on formulas (1)" and (2)" had negative values. This finding suggested that recession of LR and resection of MR did not work when using a suboptimal surgical amount, and supported the concept that the effectiveness depended on the surgical amount.

Other factors that influenced the corrective angle included postoperative exodrift, which was important for the evaluation of postoperative deviation. Hatsukawa *et al.*, in a multicenter study for children with IXT, reported that the corrective amount decreased with time [13]. Lim *et al.* showed that with older age at surgery, less postoperative exodrift was observed in subjects who underwent BLR [21]. In our previous report [18], we performed a regression analysis (dependent variable: postoperative exodrift (°); independent variable: number of days post-surgery) using the formula of curve lines. When the tangent line slope was = 0.01 (°/days), we defined the postoperative day on which alignment became stable as the "stable day." The stable day for postoperative exodrift was postoperative day 389 for patients under 10, 388 for teens, and 153 for patients aged 20 years or more. To minimize the influence of postoperative deviation by exodrift, the number of postoperative months at last examination was set to approximately 12 or more. This study included 19 cases (16%) with less than 1 year of follow-up (322 ± 27 days, 24 ± 19 years old), but the mean of all cases was over 1 year. Postoperative exodrift thus had a small impact on the results.

In formulas (1)" and (2)", the coefficients of x_3 (*patient age at time of surgery*) took positive values. The older the age at surgery, the larger the corrective angle with the same amount of surgery. Therefore, exodrift was smaller in older patients than in younger patients. In addition, in older patients the corrective angle was larger at near than at distance fixation.

In this analysis, the formulas that optimized the surgical amount for the RR surgery were defined by using preoperative deviation at distance and near fixation. The axial length or average spherical equivalent associated with postoperative deviation were not included in this analysis. The factors correlated with subject age were excluded for purposes of simplicity [22-24]. Among the total 117 subjects, 103 subjects (88%) underwent LR recession and MR resection of the same surgical amount. The number of teenagers was largest in the histogram of age distribution. This bias may have been related to the fact that the numbers of recessions and resections were identical, or the large number of teenage subjects.

The mean (±SD) of the differences between observed and calculated angles in 8 patients who underwent LR recession only were 0.4 (3.4)° at distance and 0.3 (4.8)° at near fixation. The mean (±SD) of these differences in 6 patients who underwent LR recession and MR resection with different amount of surgery were −0.5 (4.8)° at distance and −2.2 (4.4)° at near fixation. These were not outliers because recession and resection affected distant and near angles of deviation, respectively.

The success of strabismus surgery differs according to the skill and expertise of the individual surgeon, and the particular procedures in use at each institute. [3] In this study, there was a difference in the amounts of surgery for treatment of each angle of deviations, as shown in the two Tables [1,9]. The coefficients used in this study were not optimized, which may have been due to differences in the surgical approaches, the treatment of connective tissues such as Tenon's capsule, or the type of suture thread. We therefore recommend that physicians not use these coefficients, but rather rely on the formulas given above.

Surgical success rates were estimated by the differences between the calculated and observed deviations. Success rates at near fixation were lower than those at distance fixation because of the wide spectrum of differences that influence convergence. Therefore, an evaluation of success rates using values at near fixation might give inaccurate results.

In conclusion, we developed several new formulas to estimate the appropriate amount of unilateral RR surgery for IXT with consideration of the patients' age and ocular deviation at distance and near fixation. Using these formulas, we determined the optimal amount of RR surgery in IXT with a disparity in angle of deviation depending on the fixation distance.

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