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Original Article

Differences in the Stability and Amount of Postoperative Exodrift with Age after Unilateral Lateral Rectus Muscle Recession and Medial Rectus Muscle Resection of Intermittent Exotropia

Ichiro Hamasaki[a]*, Kiyo Shibata[a], Takehiro Shimizu[a], Shin Morisawa[a], Shinji Toshima[a], Manabu Miyata[b], Takashi Furuse[c], Satoshi Hasebe[c], Hiroshi Ohtsuki[d], Yuki Morizane[a], and Fumio Shiraga[a]

[a]*Department of Ophthalmology, Okayama University Hospital, Okayama 700-8558, Japan,* [b]*Department of Ophthalmology and Visual Sciences, Graduate School of Medicine and Faculty of Medicine, Kyoto University, Kyoto 606-8507, Japan,* [c]*Department of Ophthalmology, Kawasaki Hospital, Okayama 700-8505, Japan,* [d]*Department of Ophthalmology, Okayama Saiseikai General Hospital, Okayama 700-8511, Japan*

We investigated variances in the stability and amount of postoperative exodrift among age groups of intermittent exotropia (XPT) patients who underwent unilateral lateral rectus muscle recession and medial rectus muscle resection. We analyzed the cases of 110 consecutive patients who underwent the surgery in 2004-2011, dividing the patients into groups by their age at surgery: <10, 10-19, and ≥ 20 years. 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) for each group, we defined the numbers of days until alignment became stable as the 'stable days.' We evaluated the between-group differences in the amount of exodrift calculated for the stable days. The coefficients and coefficients of determination for the fitting curves were: <10 year group: $f(x)=12.2\ (1-e^{-0.0183x})$ ($r^2=0.588$, $p<0.05$); 10-19 year group: $f(x)=10.0\ (1-e^{-0.0178x})$ ($r^2=0.453$, $p<0.05$); ≥ 20 year group: $f(x)=3.40\ (1-e^{-0.0382x})$ ($r^2=0.217$, $p<0.05$). There were 389, 388, and 153 stable days, and the estimated postoperative exodrift with long-term follow-up was $11.5\pm 3.7°$, $9.3\pm 4.4°$, and $4.1\pm 3.6°$ for the <10 year, 10-19 year, and ≥ 20 year groups, respectively (≥ 20 year vs. other 2 groups, $p<0.05$). Longer periods and more postoperative exodrift were associated with younger age at surgery. The postoperative evaluation was approx. ≥ 1 year post-surgery in patients aged <20. These findings may contribute to evaluating XPT's success rate and prognoses.

Key words: intermittent exotropia, postoperative exodrift, recession, resection procedure, strabismus surgery

Regarding intermittent exotropia (XPT), there is no consensus on the optimal timing of surgery, the optimal surgical procedure, the optimal amount of surgery, the success rate, or the criteria for a successful outcome. Ocular alignment in patients with intermittent XPT usually returns to exodeviation after strabismus surgery, resulting in postoperative exodrift [1-7]. Choi *et al*. observed approx. 20 prism diopters (PD) of postoperative exodrift after unilateral lateral rectus (LR) muscle recession and a medial rectus (MR) muscle recession/resection procedure (RR) [1]. Most studies also suggest that the initial postoperative ocular alignment should be an esotropic overcorrection [8-14].

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*Corresponding author. Phone : +81-86-235-7297; Fax : +81-86-222-5059
E-mail : hamasaki_16@okayama-u.ac.jp (I. Hamasaki)

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Many researchers have thus assumed that an initial surgical overcorrection of 10-20 PD results in a higher success rate compared to either undercorrection or initial orthophoria.

Postoperative exodrift makes it difficult to evaluate the success rate for surgery in XPT. The evaluation of the success rate of XPT surgery is limited by the variability in both the length of the follow-up period and the criteria used to determine surgical success. However, the surgery success rate tends to decrease as the postoperative follow-up time is increased [2]. Evaluations of the success rate of XPT surgery can be expected to be more accurate when a long-term follow-up is used rather than a short-term follow-up, but the former involves greater time and effort; thus, few studies have included long-term follow-ups [15-17]. Studies of postoperative exodrift are therefore needed to identify definitive criteria for the length of time of stability before the recurrence of exodeviation.

The patient's age at surgery has been shown to be significantly correlated with postoperative exodrift [3]. Additional studies are thus necessary to elucidate the number of stable days and the amount of postoperative exodrift in different age groups at surgery. We conducted the present study to investigate the number of stable days and the amount of postoperative exodrift in XPT patients in 3 age groups.

Methods

Patients. We retrospectively analyzed the cases of the series of 110 patients with XPT who underwent the recess-resect (RR) procedure (*i.e.*, unilateral lateral rectus muscle recession and medial rectus muscle resection) between April 2004 and December 2011 at Okayama University Hospital. All of the patients were diagnosed with XPT, defined at distance and near deviations within 15 PD. Patients were excluded if they had preoperative vertical deviation >5 PD at distance or near fixation, dissociated vertical deviation, any history of previous strabismus surgery, had undergone surgery with vertical transposition to correct an A and V pattern, had undergone surgery with the use of an adjustable suture method, were diagnosed with an early onset of XPT, when informed consent could not be obtained, or when there was any history of other disease-causing ocular deviations (*e.g.*, thyroid ophthalmopathy, myasthenia gravis, internuclear ophthalmoplegia, high-grade myopia, paretic strabismus, sensory strabismus, or other neurological disorders). Subjects with refractive errors wore corrective lenses.

Table 1 summarizes the patients' characteristics. The extent of preoperative exodeviation at distant fixation was determined for each patient by the prism adaptation test using the Fresnel Press On Prism (Health Care Specialties Division/3M, St. Paul, MN, USA) to neutralize the angle of deviation. The prism power was adjusted according to the responses to deviation as determined by the prism cover test (PCT), and the test was repeated at 20-min intervals until no additional prisms were required to neutralize the distance deviation. The amount of surgery was determined by measurements at distant fixation [18]. The undercorrection was required to avoid diplopia after surgical overcorrection in adult patients. Measurements in prism diopter units were converted to degrees. The PCT for the angle of deviation was conducted within approx. 1 week and at 1, 3, 6, 12, 18, and 24 months after surgery. Because of the small angle of deviation after surgery, the variability of those tested with PCT was considered to be small [19].

Postoperative exodrift was defined as the change in the angle of deviation from the postoperative initial examination to final examination and was calculated for all of the examinations. The data were retrospectively reviewed for patients who postponed their further visits because of personal reasons after leaving the clinic. All of the participants gave their informed consent for their data to be analyzed and published. The protocol conformed to the Declaration of Helsinki and was approved by the institutional review board of the Okayama University Hospital and the affiliated hospital for col-

Table 1 Patient characteristics

Age at surgery (mean ± SD); (range)	23 ± 21 years (5–79 years)
Male/Female	51/59
Right/Left eye operated	48/62
LR recession (mean ± SD) (range)	6.5 ± 1.3 mm (4.0–9.0)
MR resection (mean ± SD) (range)	6.5 ± 1.3 mm (4.0–9.0)
Preoperative exodeviation at 5 m (mean ± SD); (range)	20.5 ± 6.6° (10.3–42.5)
Postoperative first examination day (mean ± SD); (range)	7.0 ± 2.0 days (1–15)

Table 2 Patient group details

	<10 year group	10–19 year group	≥20 year group	*P* value
n	33	38	34	
Age at surgery (years)	6.5 ± 1.2	12.8 ± 2.3	46.0 ± 18.2	
Preoperative angle of exodeviation (degrees)	18.3 ± 4.5	22.0 ± 4.1	30.7 ± 8.6*	<0.05
Amount of surgery (mm)	13.0 ± 2.4	12.7 ± 2.7	13.1 ± 2.9	0.72
Corrective angle at the postoperative initial examination (degrees)	25.7 ± 6.3	23.8 ± 6.5	25.0 ± 6.2	0.51

The amount of surgery is the sum of the amount (mm) of LR recession and MR resection using the RR procedure. The corrective angle at the postoperative initial examination is difference in angle of exodeviation between at before surgery and at the postoperative initial examination. *Significant difference between ≥20 year groups. and others, using the Kruskal-Wallis test ($p<0.05$).

laborative research.

To compare the differences in the stability and amounts of postoperative exodrift between patients of different ages, we divided the 110 patients into 3 groups according to their age. In the <10 year group (n=33), the patients were <10 years old; in the 10-19 year group (n=38), patients were 10-19 years old; and in the ≥20 year group (n=34), patients were ≥20 years old. Table 2 provides the details of each age group.

Analyses. We performed a regression analysis with postoperative exodrift as the dependent variable and the number of days after surgery as the independent variable. The coefficients of the formula provided below were revealed by the regression analysis performed with the 'solver' function in Excel 2016 software for Windows (Microsoft, Redmond, WA, USA).

$$f(x)=a(1-e^{bx})$$

where 'f(x)' represents the postoperative exodrift (in degrees), 'x' is the number of days after surgery, and 'a' and 'b' are coefficients. The coefficients for each group were used in the formula. The value 'x' was defined as the number of stable days and was determined for each group when the formula was differentiated and the slope of the formula equaled 0.01. Differences in the number of stable days between the groups were then investigated.

To compare postoperative exodrift in the three age groups, we identified the coefficients of the formula for each patient using the same regression analysis method. The limit as 'x' (*i.e.*, the number of days after surgery) approaches infinity of the formula was the value of coefficient 'a.' The value of coefficient 'a' for each patient was defined as the estimated postoperative exodrift with long-term follow-up. The 'a' coefficients of the 3 groups were was compared with the Kruskal-Wallis test. IBM SPSS Statistics for Windows, ver. 22.0 (IBM, Armonk, NY, USA) was used for all statistical analyses.

Results

Fig. 1 shows the results of the line chart for each patient and the fitting curves for each group in terms of postoperative exodrift. The coefficients and coefficients of determination for the fitting curves were a=12.2, b=−0.0183, and $r^2=0.588$ ($p<0.05$) for the <10 year group; a=10.0, b=−0.0178, and $r^2=0.453$ ($p<0.05$) for the 10-19 year group; and a=3.40, b=−0.0382, and $r^2=0.217$ ($p<0.05$) for the ≥20 year group. The numbers of stable days were 389, 388, and 153 for the respective groups. Postoperative exodrift was low after the first postoperative year but continued to gradually change in some patients over time.

Fig. 2 provides box plots for the calculated values of postoperative exodrift for each group. The calculated values of postoperative exodrift between each group were significantly different ($p<0.05$). The estimated postoperative exodrift with long-term follow-up was 11.5±3.7°, 9.3±4.4°, and 4.1±3.6° for the <10 year, 10-19 year, and ≥20 year groups, respectively, there was a significant difference between the ≥20 year group and the other 2 groups ($p<0.05$).

Discussion

Our present findings revealed that the older the XPT patient was at surgery, the lower the number of stable days of recurrence and the less postoperative exodrift could be expected. The number of stable days and the amount of postoperative exodrift could therefore be estimated preoperatively using the patient's age at surgery. The maximum number of stable days after surgery

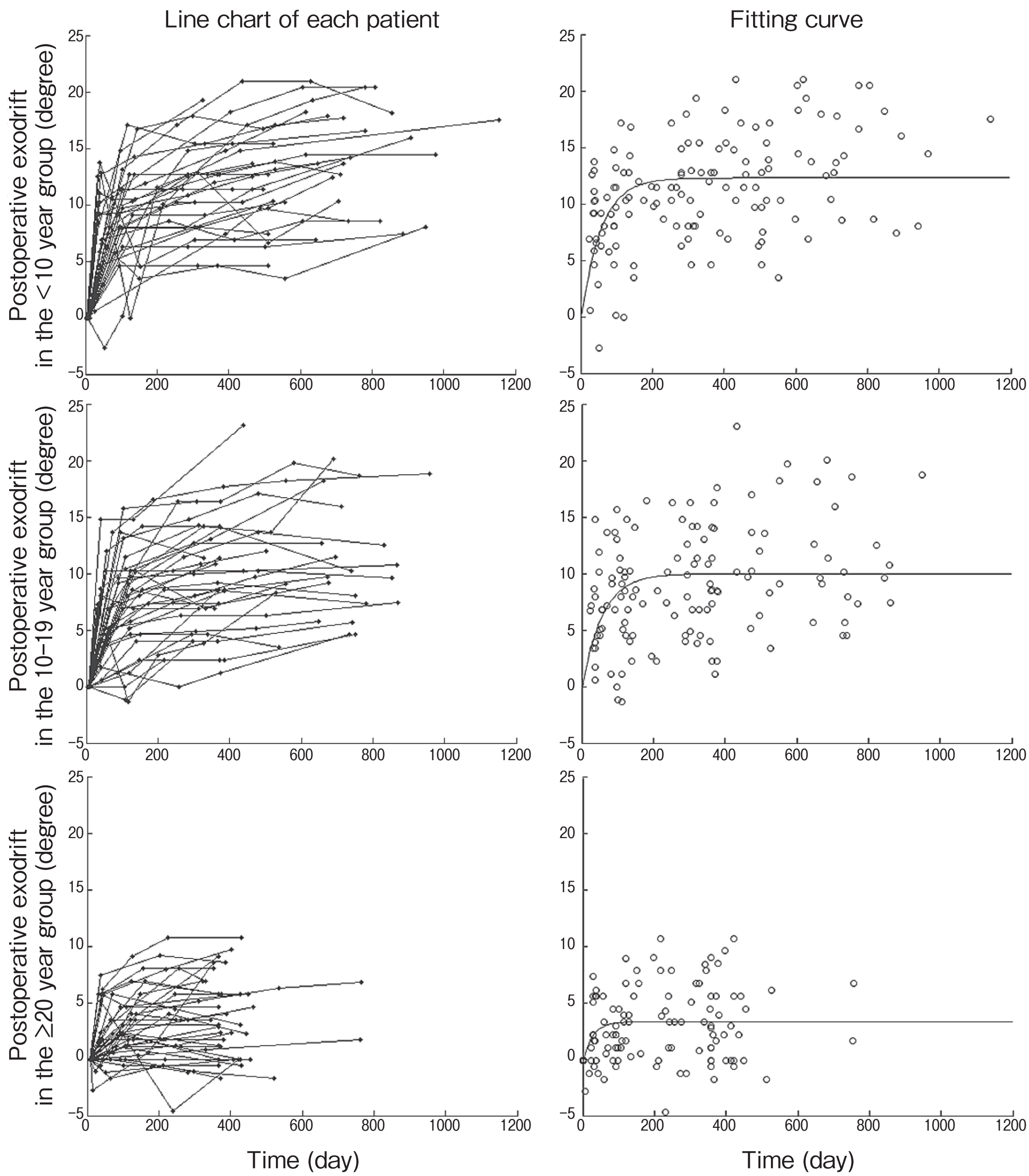

Fig. 1 Line charts and fitting curves. *Left column*: The line chart for each patient in each group in terms of postoperative exodrift. *Right column*: Plots for each patient and the fitting curves for each group.

was 389. The angle of deviation after ≥1 postoperative years was demonstrated to be useful for evaluating the surgical success rate, based on the stability of the age groups. For the patients in our ≥20 year group, ocular alignment was particularly stable for ≥6 months after surgery.

Postoperative exodrift after the first postoperative year was nearly completely stable in this study. Heo *et al.* reported that the mean amount of exodrift at distant fixation was 0.3° from 12 months after surgery to the last follow-up in patients who had ≥20 PD overcorrection at either near or distant fixation on day 1 after the RR pro-

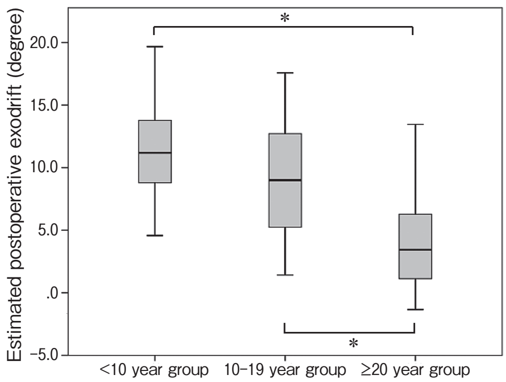

Fig. 2 The calculated values of postoperative exodrift in each group. The maximum (*top error bar*), third quartile (*top shaded section*), median (*middle line*), first quartile (*lower shaded section*), and minimum (*bottom error bar*) of the estimated postoperative exodrift for the <10 year, 10−19 year, and ≥20 year groups. *$p < 0.05$ between groups, Kruskal-Wallis test.

cedure [20]. Choi *et al.* reported that the mean amount of exodrift was 2.05 PD from 1 year postsurgery to the last month of follow-up, which was 47.8 ± 16.9 months for the RR procedure in their study [1]. In an investigation by Lee *et al.*, the mean amount of exodrift was small, with a postoperative value of 2.29 PD between the time at the first and second years after bilateral lateral rectus muscle recession (BLR) and RR procedures [21]. Moreover, the amount of exodrift was small after the first postoperative year in a study by Scott *et al.* investigating BLR, RR, 3-4 horizontal muscles, and other procedures [14].

In another study, patients with infantile XPT were divided into two groups with a cutoff exodeviation of 10 PD at postoperative 1 year [22]. There was no significant difference in the postoperative alignment at postoperative day 1 or month 1 between the two groups, which may have been influenced by the range in the amount of postoperative exodrift. The use of a cutoff esodeviation of 17 PD at 1 day after surgery for patients <20 years old [23] revealed a significant difference in esodeviation under or over 10 PD at 6 months postsurgery between the 2 groups ($p < 0.001$). This may have been caused by a stable rate of exodrift, which may have become significantly weaker or absent at 1 year after surgery. Thus, the success rate of surgery should not be evaluated too soon postoperatively, and the postoperative evaluations of consecutive esotropia within 6 months may be premature.

In some of the patients in the present study, postoperative exodrift occurred after approx. 1 year, over a longer period of time. The reason why postoperative exodrift continues to gradually change is unclear, although some researchers have proposed possible explanations. Pineles *et al.* suggested that concomitant XPT is due to a central disorder of vergence control caused by a small amount of exodrift in patients with pattern strabismus that may have resulted from mechanical or orbital factors [24]. Lewis *et al.* stated that the proprioception function of the extraocular muscles contributes to the long-term adaptive mechanisms that regulate ocular alignment [25].

Moreover, Heo *et al.* reported that in a limited number of patients with the mean age at surgery of 6.8 ± 2.1 years and an overcorrection of ≥20 PD on the first postoperative day, recurrence rates were higher in the RR group than in the BLR group [20]. Kim *et al.* also reported more exodrift using the RR procedure compared to contralateral LR recession in patients with recurrent XPT [26]. This difference in surgical procedures may be related to proprioception function of the extraocular muscles. Steinbach *et al.* suggested that tendon organs are important factors in eye position proprioception [27], and that damage to the tendons of extraocular muscles during surgery could consequently influence postoperative proprioception. They observed a longer period of exodrift for the RR procedure, which included the resection of the tendon organ of MR, than for the BLR procedure. This finding suggests that removing proprioceptors of the muscle tendons influenced long-term exodrift.

In our patients, postoperative exodrift was stable for approx. 1 year after the RR procedure was used. Bilateral or unilateral LR recession resulted in shorter periods of stability compared to RR. Thus, postoperative evaluations for these procedures are best performed after more than 1 year.

In our cohort, the older the patient at surgery, the smaller the amount of postoperative exodrift was observed. Kim *et al.* reported that the postoperative exodrift of recurrent XPT patients was significantly lower than that of both XPT patients with a single surgery and patients after the first of 2 surgeries ($p < 0.001$) [28]. A patient's age increases with reoperation since a reoperation is performed after the first operation, and thus, an association between age at surgery and exodrift should be expected. This age-related difference is likely due to the degeneration of the orbital connective tissue and/or proprioceptors with aging.

When we compared the stability and amount of postoperative exodrift between the present three age groups, a significant difference was revealed in the preoperative exodeviation between the ≥20 year group and the <10 year and 10-19 year groups; however, a significant difference was not found in the amount of surgery because of the undercorrection required to avoid postoperative overcorrection in adult patients (the ≥20 year group). In addition, no significant difference was observed in the corrective angle at the postoperative initial examination. In the ≥20 year group, this may have influenced postoperative exodrift because postoperative overcorrection is also correlated with postoperative exodrift [3].

Our analyses demonstrated that the younger the patient at surgery, the longer the period of stability and the larger the amount of postoperative exodrift was observed. We determined that postoperative evaluation is best at approx. 1+ year after surgery. These findings should be useful in the evaluation of the success rate and prognosis following XPT surgery.

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