• Clinical Research •

Clinical efficacy of the partial rectus muscle transportation procedure for paralytic strabismus

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Abstract

● **AIM:** To analyze the clinical efficacy of the partial rectus muscle transportation (PRT) procedure for paralytic strabismus due to single rectus muscle palsy.

● **METHODS:** In total, 28 patients (31 eyes) who underwent the PRT procedure for paralytic strabismus due to single rectus muscle palsy were retrospectively examined. The following data were collected pre- and postoperatively: angle of deviation in the primary position, presence of diplopia in the primary position, presence of compensatory head posture, and motility of the affected eye. The follow-up period was 6mo.

● **RESULTS:** Based on the preoperative and intraoperative findings, different operations were performed: 2 eyes were treated with PRT, 26 eyes were treated with PRT combined with the recession of the antagonist muscle (Am) of the paralytic rectus muscle, and 3 eyes were treated with PRT along with the recession of the Am and the yoke muscle (Ym). On the first day after the operation, 24 patients were found to be orthophoric in the primary position, without diplopia or abnormal head posture. Moreover, 2 patients with monocular lateral rectus muscle palsy had mild overcorrection to 5 prism diopters (PD) and 8 PD, respectively, whereas 2 patients with binocular lateral rectus muscle palsy had mild undercorrection to 8 PD and 10 PD, respectively. During the 6-month follow-up period, the mean deviation was rectified from 96.79±41.21 PD to 0.64±2.38 PD (t=12.48, P<0.001), whereas the deviations in the 2 patients with mild overcorrection were corrected to orthotropia. The mean preoperative limitation of motility improved from -4.55±0.51 to -2.65±0.61 (t=-15.13, P<0.001) after 6mo postoperatively.

● **CONCLUSION:** PRT is an effective treatment for complete paralytic strabismus due to single rectus muscle palsy, and can achieve stable clinical efficacy.

● **KEYWORDS:** ophthalmoplegia; strabismus; rectus; transposed procedure

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INTRODUCTION

Complete paralytic strabismus is usually associated with a large angle of deviation and marked motility restriction without the ability to reach the mid-line. In these patients, the main goals of surgery are to improve the cosmetic appearance and ocular motility, eliminate diplopia, and expand the binocular visual field. For cases with complete paralytic strabismus, the regular supra-maximal recession-resection procedure is not completely effective, and usually results in undercorrection, recurrence, or retained motility limitations[1]. In early 20th century, Hummelsheim[2] described a partial rectus muscle transportation (PRT) technique for the treatment of sixth nerve palsy, wherein the lateral portion of the superior and inferior rectus muscle was transposed to the insertion site of the palsy-affected muscle. The efficacy of PTR or its modifications in the treatment of paralytic strabismus has been widely accepted, although the results have varied in different reports and primarily depend on the degree of lateral rectus muscle palsy. For patients with third nerve palsy, the efficacy of PRT is difficult to compare and evaluate due to the varied clinical manifestations. In the present study, we only assessed cases of paralytic strabismus due to single rectus muscle palsy, to objectively evaluate the efficacy of PRT in the treatment of complete paralytic strabismus.

SUBJECTS AND METHODS

Ethical Approval This retrospective series of case study collected the clinical data of patients with complete paralytic strabismus due to single rectus muscle palsy, who were underwent the PRT procedure in the Eye Center of Xiangya Hospital, Central South University. All examinations obtained the patient's informed consent and all patients signed a consent form before surgery. The examination study was in accordance with the Declaration of Helsinki.

Subjects This study is a retrospective review of patients with complete paralytic strabismus due to single rectus muscle palsy who underwent the PRT procedure between January 2011 and October 2017 in the Eye Center of Xiangya Hospital, Central South University. A total of 31 eyes of 28 patients (20 male and 8 female patients) were included, and all the patients were followed for 6mo. The mean patient age was 40.32±16.30y (range 3-63y). The palsy-affected muscles included the lateral rectus (22 eyes of 19 patients), medial rectus (2 eyes of 2 patients), superior rectus (4 eyes of 4 patients), and inferior rectus (3 eyes of 3 patients). Among these cases, 21 eyes of 18 patients were affected by craniocerebral trauma, 5 eyes of 5 patients had a congenital cause for the disease, 2 eyes of 2 patients were affected following orbital tumor removal, 1 eye was affected due to ocular trauma, and 2 eyes of 2 patients developed the condition due to an unknown cause.

Methods of Examination All patients underwent complete ophthalmic evaluation, including vision, intraocular pressure, refractive status, ocular anterior segment, and ocular fundus. The following examinations of the strabismus were collected pre- and postoperatively: 1) evaluation of the motile capacity of monocular and binocular eyes (eyes without the ability to move beyond the mid-line were diagnosed with complete palsy); 2) measurement of the deviation angle using an alternating prism with the cover test at 5 m and 0.33 m; and 3) examination of the presence of diplopia and compensatory head posture. Intraoperative forced duction testing (FDT) was performed in all cases under topical anesthesia or general anesthesia. The ductions were graded from 0 to -5[3-4]: 0 indicates full ocular movement, -5 refers to inability to reach the mid-line, -4 refers to the ability to only reach the mid-line, and grades from - 3 to -1 refer to differing abilities to reach the mid-line from the normal position.

Surgical Management All surgical operations were performed by the same experienced surgeon. All adult patients preferred surface anesthesia, except for one who could not tolerate it; the pediatric patients received general anesthesia. Based on the FDT performance, the recession of the antagonist muscle (Am) procedure was selectively applied (Figure 1). If the FDT outcome was negative, the partial transportation (hemitransposition) was first performed for the rectus muscles adjacent to the insertion site of the paralyzed muscle. However, if the improvement was not satisfactory, further recession of the Am was performed. If the FDT outcome was positive, Am recession was performed before the PRT procedure. Additional recession of the yoke muscle (Ym) was performed if the deviations persisted. The detailed hemitransposition procedure was performed as follows: the conjunctiva was opened to expose and separate the 2 rectus muscles adjacent to the paralyzed muscle; the width of the rectus muscle to be transposed was measured, and a short muscle hook was used to bluntly dissect each of the rectus muscles into equally wide strips; the rectus muscles were split from the insertion site to a length of 12-14 mm; the halves adjacent to the paralyzed muscle were double-loop sutured with 5-0 vicryl suture, and were transposed close to the margin of the paralytic rectus; and the ciliary anterior artery was carefully conserved during the surgery. The most important technique was that fixing the transposed rectus muscle and the backward displaced Am by an adjustable suture after the transposition or the recession, and then evaluating the patient's residual deviation by corneal light reflection test at operation. If the correction was not satisfactory, the transposed muscles were further resected by 3-7 mm and sutured to achieve an augmented transposition, and/or performed a lager amount of recession of Am. Our surgical plan was not a quantitative one preoperatively, but rather an adjustable plan during surgery. During the operation under surface anesthesia, the final amount of resection of transposed rectus muscle or recession of the Am and Ym was adjusted according to the muscle force of the transposed rectus muscle, the extent of Am contracture and the intraoperative angle of deviation.

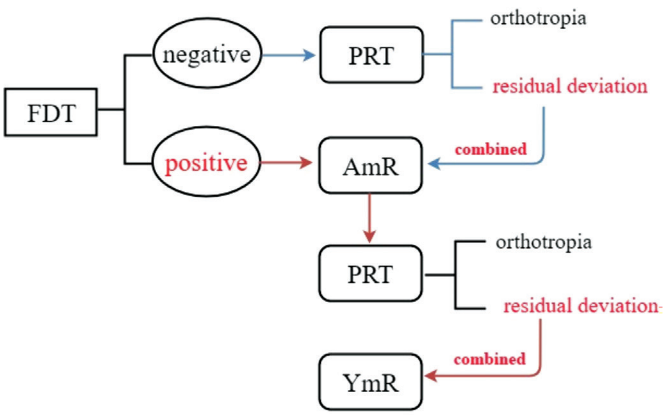

Figure 1 Flow chart for selecting a surgical plan FDT: Forced duction testing; PRT: Partial rectus muscle transportation; AmR: Recession of the antagonist muscle of the paralytic rectus muscle; YmR: Recession of the yoke muscle of the paralytic rectus muscle.

Efficacy Evaluation Criteria Surgical management was considered to be satisfactory when the postoperative degree of prism was <5 prism diopters (PD), and diplopia and compensatory head posture had both disappeared. A postoperative degree of prism of <10 PD was defined as mild undercorrection or overcorrection.

Statistical Analysis SPSS 17.0 statistical software was applied to perform Mann-Whitney *U* test on the parameters: to compare the clinical manifestations of preoperative and postoperative changes in all patients, the clinical efficacy by 3 different groups, and the effects of 2 surgical methods for the treatment of lateral rectus palsy. A *P* value of 0.05 was chosen as the level of statistical significance.

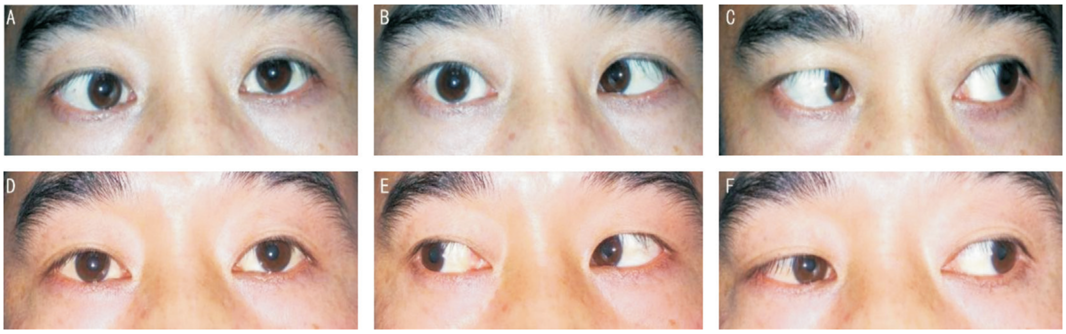

Figure 2 Preoperative and 6mo postoperative photographs of a 34-year-old male patient with right lateral rectus palsy The patient was caused by cranio cerebral trauma for 7mo. A-C: Preoperative photographs; D-F: Postoperative photographs; A, D: The primary position; B, E: The secondary position of turn rightward; C, F: The secondary position of turn leftward.

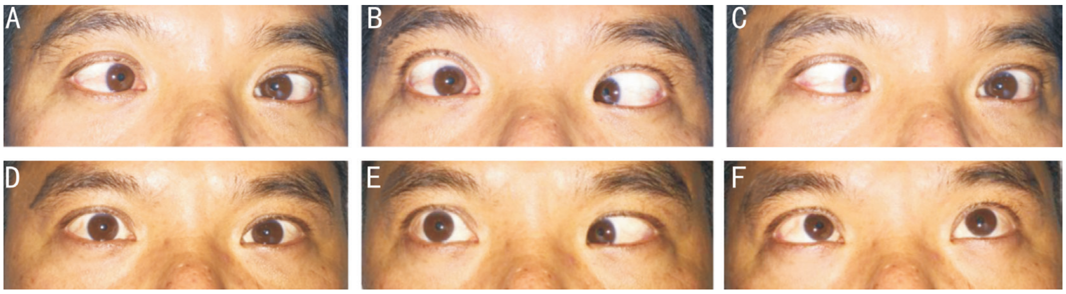

Figure 3 Preoperative and postoperative photographs of a 34-year-old male patient with bilateral rectus palsy The patient was caused by cranio cerebral trauma for 2y and 3mo; A-C: Preoperative photographs; D-F: Postoperative photographs; A, D: The primary position; B, E: The secondary position of turn rightward; C, F: The secondary position of turn leftward.

RESULTS

Among 31 eyes of 28 patients with complete paralytic strabismus, the mean deviation was 115.53±33.78 PD (range 45-140 PD) for 22 eyes of 19 patients with lateral rectus palsy, 75 PD and 110 PD for 2 eyes of 2 patients with monocular medial rectus palsy, 52.50±12.58 PD (range 40-70 PD) for 4 eyes of 4 patients with monocular superior rectus palsy, and 40 PD for 3 eyes of 3 patients with monocular inferior rectus palsy.

Based on the examination findings, 3 different approaches were used for the PRT procedure: 1) PRT alone in 2 patients, including 1 with monocular superior rectus palsy and another with monocular inferior rectus palsy; 2) PRT combined with Am recession in 26 eyes, including 15 that also underwent augmented transposition; and 3) augmented PRT along with Am and Ym recession in 3 patients with monocular lateral rectus, medial rectus, or superior rectus palsy. In those patients, the amount of Am recession ranged from 4.5 to 10 mm. For 19 eyes with lateral rectus palsy, the recession amount of the medial rectus ranged from 5 to 10 mm. For 2 eyes with monocular medial rectus palsy, the recession amounts of the lateral rectus were 8 and 10 mm, respectively. For 2 eyes with monocular inferior rectus palsy, the recession amounts of the superior rectus were 5 and 6 mm. For 3 eyes with monocular superior rectus palsy, the recession amount of the inferior rectus was 4.5 mm in a pediatric patient with congenital ptosis, and was 5 and 5.5 mm in the 2 other acquired cases. In the augmented PRT procedure, the transposed muscles were resected by 3-7 mm before transposition. The average amount of Ym recession was 6.3 mm/eye (range 5-8 mm), including 6 mm to the medial rectus of a patient with lateral rectus palsy in the fellow eye, 8 mm to the lateral rectus of a case with a monocular medial rectus palsy, and 5 mm to the inferior rectus of a patient with superior rectus palsy.

Among the 28 patients, the mean preoperative deviation was 96.79±41.21 PD. On the first day after the surgery, 24 patients were orthotopic, and the mean postoperative deviation was 1.18±3.04 PD (P<0.05). Among them, 2 patients with binocular lateral rectus palsy had residual exotropia ≤10 PD, and 2 patients with monocular lateral rectus palsy had overcorrection ≤10 PD. During the 6-month follow-up period, the mean deviation decreased to 0.64±2.38 PD (t=12.48, P<0.001). This reflects whereas the primary position alignment in the others remained stable. All eyes with paralysis were unable to move beyond the mid-line preoperatively, and the average motility grade was -4.55±0.51. Of these, 17 eyes were graded as -5 and 14 eyes were graded as -4. At 6mo after the surgery, marked improvement was observed in the ocular motility of eyes with paralysis (Figures 2-6); the average grade improved to -2.65±0.61 (t=-15.13, P<0.001), including to -4 in 1 eye, -3 in 19 eyes, -2 in 10 eyes, and -1 in 1 eye. Preoperative diplopia was found in 23 patients with acquired complete paralytic

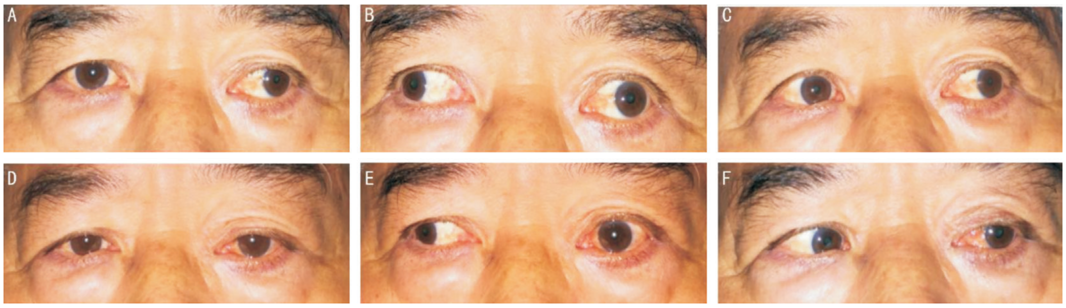

Figure 4 Preoperative and postoperative photographs of a 63-year-old male patient with left medial rectus palsy The patient presented with unilateral exotropia after a surgery to treat orbital tumor 2 years ago; A-C: Preoperative photographs; D-F: Postoperative photographs; A, D: The primary position; B, E: The secondary position of turn rightward; C, F: The secondary position of turn leftward.

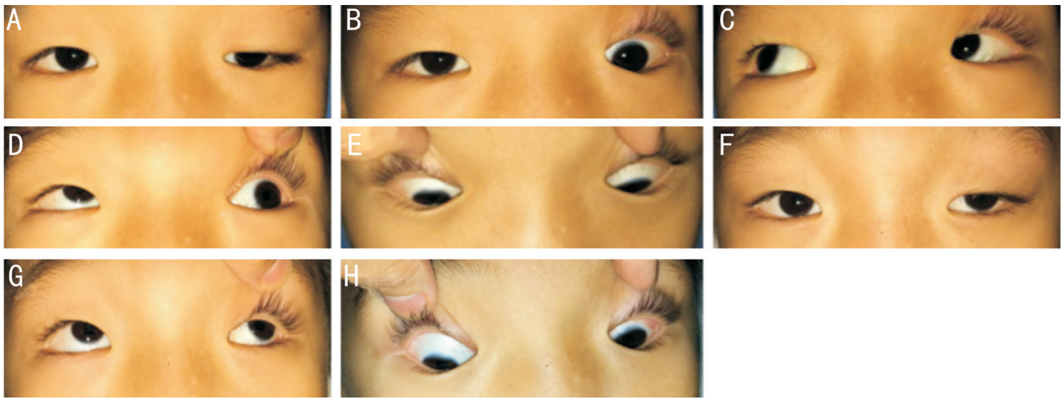

Figure 5 Preoperative and postoperative photographs of an 8-year-old male child with congenital left superior rectus and levator palpebrae superioris palsy A-E: Preoperative photographs; F-H: Postoperative photographs; A, B, and F: The primary position; C: The tertiary position of upward to the right; D, G: The tertiary position of upward to the left; E, H: The secondary position of downward.

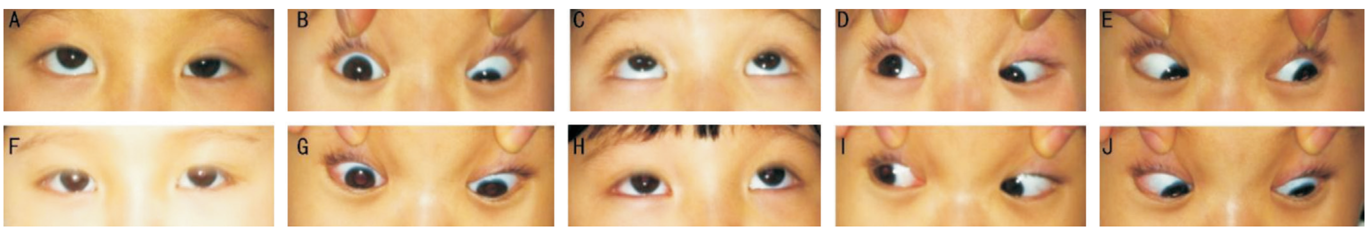

Figure 6 Preoperative and postoperative photographs of a 3-year-old female child with congenital right inferior rectus palsy A-E: Preoperative photographs; F-J: Postoperative photographs; A, F: The primary position; B, G: The secondary position of downward; C, H: The secondary position of upward; D, I: The tertiary position of downward to the right; E, J: The tertiary position of downward to the left.

strabismus. During the 6-month follow-up period, diplopia in the front field of vision was eliminated in 21 patients, whereas 2 patients with binocular lateral rectus muscle palsy were required to wear an 8 PD and a 10 PD prism to rectify diplopia. Abnormal head posture was not observed in any of the patients after surgery. No scleral perforation, anterior segment ischemia, or new-onset horizontal or vertical deviation were observed intraoperatively or during the 6-month follow-up period. Table 1 shows the preoperative and postoperative examination results of all the patients, and Table 2 shows a comparison of patients' clinical characteristics in 3 surgical techniques.

Among the 19 patients with lateral rectus palsy, all patients' FDT were positive. Therefore, all received PRT procedure combined with the recession of the Am, and one of the patients performed an additional recession of the Ym. Among them, 10 patients underwent augmented PRT, and the amount of resection was 4.58±1.83 mm. The two groups of patients with PRT and augmented PRT were compared. The results showed that there was no significant difference in age between the two groups (45.00±10.84 *vs* 45.80±6.84, $P>0.05$), and the amount of recession of the Am also showed no significant difference (6.67±1.50 *vs* 5.70±0.48, $P>0.05$). Compared to the PRT group, the augmented PRT group had a slightly larger deviation preoperatively (129.00±24.24 *vs* 100.56±37.79, $P<0.05$), and the limitation of ocular motility was more obvious (-4.83±0.39 *vs* -4.30±0.48, $P<0.05$). At 6mo follow-up, the improvement of deviation of the augmented PRT group was greater than that of the PRT group (128.20±23.97 *vs* 99.44±36.61, $P<0.05$), but

Table 1 Preoperative and postoperative (at 6mo follow up) clinical characteristics

Time	Case number	Deviation (PD)	Diplopia	Abn-head posture	Ocular motility
Preop.	28	96.79±41.21	23 (82.14%)	28 (100%)	-4.55±0.51
Postop.	28	0.64±2.38	2[a] (7.14%)	0	-2.65±0.61

Abn-head posture: Abnormal head posture. [a]Two patients had mild undercorrection (8 and 10 PD, respectively).

Table 2 Comparison of patients' clinical characteristics in 3 surgical techniques

Surgical technique	Total patients	Deviation (PD)		Ocular motility		Diplopia		Abn-head posture	
		Preop.	Postop.	Preop.	Postop.	Preop.	Postop.	Preop.	Postop.
PRT	2	40[a]	0	-4	-3	1	0	2	0
PRT+AmR	23	101.96±40.30	0.78±2.61	-4.54±0.51	-2.62±0.64	21	2[d]	23	0
PRT+AmR+YmR	3	95[b]	0	-5	-2.67[c]	1	0	3	0

PRT: Partial rectus muscle transportation; AmR: Recession of the antagonist muscle of the paralytic rectus muscle; YmR: Recession of the yoke muscle of the paralytic rectus muscle; PD: Prism diopters; Preop.: Preoperative; Postop.: Postoperative (at 6mo follow up); Abn-head posture: Abnormal head posture. [a]The primary deviation of the two patients both were 40 PD; [b]70, 75, and 140 PD for the 3 patients, respectively; [c]-3, -3 and -2 for the 3 patients, respectively. [d]Two patients had mild undercorrection (8 and 10 PD, respectively).

Table 3 Comparison the clinical efficacy of PRT *vs* augmented PRT to treat patients with lateral rectus palsy (*n*=19, 22 eyes)

Parameters	Surgical technique[a]		*P*
	PRT+AmR (*n*=9, 10 eyes)	Augmented PRT+AmR (*n*=10, 12 eyes)	
Age (y)	45.00±10.84	45.80±6.84	0.683[c]
Resection amounts before PRT (mm)	-	4.58±1.83	-
Recession amounts of AmR (mm)	5.70±0.48	6.67±1.50	0.101[c]
Recession amounts of YmR (mm)	-	6[b]	-
Preop. deviation (PD)	100.56±37.79	129.00±24.24	0.045[c]
Improvement of deviation (PD)	99.44±36.61	128.20±23.97	0.031[c]
Preop. ocular motility	-4.30±0.48	-4.83±0.39	0.013[c]
Improvement of ocular motility	-2.00±0.82	-2.08±0.51	0.794[c]

PRT: Partial rectus muscle transportation; AmR: Recession of the antagonist muscle of the paralytic rectus muscle; YmR: Recession of the yoke muscle of the paralytic rectus muscle; PD: Prism diopters; [a]All patients with lateral rectus palsy performed AmR technique, because the FDT of them were all positive; [b]Only one patient performed an additional 6 mm recession of the YmR; [c]Mann-Whitney *U* test.

there was no significant difference in the improvement of eye movement between the two groups (-2.08±0.51 *vs* -2.00±0.82, $P>0.05$). Table 3 shows the clinical efficacy of PRT compared to augmented PRT to treat patients with lateral rectus palsy.

DISCUSSION

Paralytic strabismus can be classified as complete palsy and partial palsy. For patients with partial rectus palsy and sufficient residual motility that allows their eyes to move beyond the mid-line, paralytic rectus muscle strengthening (*via* plication, resection, or anterior migration of muscle), with or without additional recession of Am and Ym, may offer suitable clinical efficacy. However, for complete paralytic strabismus, the traditional procedures may not achieve satisfactory outcomes, and recrudescence often occurs. As paralytic rectus muscles completely lose their function, reinforcement alone will not be sufficient to regain their strength; however, transposition of healthy muscles towards the palsy-affected muscle could offer sufficient support. The transposition procedure involves a change in the insertion positions of 2 adjacent muscles of the palsy-affected muscle, and thus, the direction of the force vectors of the transposed muscles changes towards the direction of action of the palsy-affected muscle. Thus, the palsy-affected muscle can gain support for the improvement of motility, and consequently for the resolution of ocular deviation[5-6]. The PRT procedure was first described by Hummelsheim for the management of complete abduction deficits, and the common complications of PRT include new-onset horizontal or vertical deviation and anterior segment ischemia[7-8]. In order to reduce the incidence of those complications, various modifications have been proposed[9-13]. In 1964, Jensen[14] introduced a muscle union procedure without muscle tenotomy to reduce the risk of anterior segment ischemia. Park *et al*[9] applied the muscle union procedure to treat 27 patients with paralytic strabismus, and achieved a mean correction of 48 PD. Laby and Rosenbaum[15] reported an adjustable vertical muscle transposition technique to address the complication of vertical deviation. Holmes *et al*[16] indicated that preoperative cornea marks of 12 o'clock and 6 o'clock positions could be used to prevent vertical deviation. To enhance the strength of the transposed muscle, Schillinger[17] described a full rectus muscle transposition (FRT) procedure, whereas Foster[18] described an FRT procedure with posterior fixation sutures of the transposed muscles. del Pilar González and Kraft[10] compared 3 different FRT procedures, including FRT alone, augmented FRT with 4-mm resections prior to reinsertion, and FRT with myopexy sutures, and the mean corrections were 36.0, 46.4, and 41.3 D, respectively. MRI indicated that the Foster procedure shifted the pulley of the transposed muscles posteriorly and narrowed the gap between the palsy muscle and transposed muscles[5]. The FRT procedure was usually performed without any antagonism muscle recession, due to the high risk of anterior segment ischemia. In 2000, Brooks *et al*[19] introduced an augmented PRT procedure with 4-8-mm resections prior to reinsertion, this procedure achieved a similar effect as FRT[7,10,19-20]. In the report by Brooks *et al*[19], a mean correction of 52 PD was achieved by augmented PRT, whereas in a report by Couser *et al*[7], a mean correction of 39 PD was achieved. Although the clinical effects of PRT vary in different studies, in general, the transposition procedure of the rectus muscle remains the major surgical treatment for complete paralytic strabismus.

Paralytic strabismus is often accompanied by the contracture of the antagonism muscle, and hence, the simultaneous weakening of the Am is required. However, the risk of anterior segment ischemia increases if muscle union or FRT in combination with the weakening procedure are simultaneously performed. Hence, the procedure should be divided into multiple sessions to lower the risk. The PRT alone involves the transposition of a half strip of the normal muscle to the insertion site of the palsy-affected muscle with or without the resection of the transposed muscle strip for an augmented procedure. If the procedure is carefully performed, the anterior ciliary vessels of the untouched rectus can be preserved, and the risk of anterior segment ischemia can be minimized. Hence, it is possible to perform the PRT procedure in combination with Am recession in a single session for the management of complete paralytic strabismus, and suitable clinical outcomes have been achieved by intraoperatively adjusting the amount of Am recession or the length of the transported muscle strip[19]. Couser *et al*[7] reported that the augmented Hummelsheim procedure with Am recession had better clinical effects, as compared to other procedures. All the cases enrolled in the present study were treated in a single session, and the anterior ciliary vessels were carefully separated and preserved during muscle transposition. Anterior segment ischemia was not observed in any of the cases. All patients had slight to moderate improvement in motility. Diplopia in the primary eye position was not observed in 21 patients at the final follow-up. The binocular visual functions had recovered and compensatory head posture disappeared in the acquired complete strabismus patients. These results are consistent with those reported by Liu *et al*[4]. New-onset horizontal or vertical deviation are usual complications of rectus muscle transposition, and need to be carefully considered. Although some reports indicate that vertical deviations or torsional diplopia do not occur after sole transposition of the superior rectus[12], the findings are inconsistent[13,21]. A symmetric transposition was carefully performed during surgery in our study, and no unexpected deviation was observed.

PRT is effective for the treatment of complete rectus palsy or muscle absence including the lateral rectus, medial rectus, superior rectus, and inferior rectus; however, it is difficult to preoperatively design a precise surgical plan. As different patients may have different pathogenesis and differing anatomy factors, and the forces of the Am and Ym vary may with disease progresses, the management of complete strabismus remains difficult to predict, particularly in long-standing secondary cases. Complete rectus muscle palsy may trigger a series of secondary changes over time: chronically abnormal eye alignment and motility limitation could result in Am contracture, the forces of other extraocular muscles may change due to the compensatory adjustment, and the induced torsion *via* contracture would consequently aggravate the deviation. Therefore, preoperative FDT is essential for all patients. If the FDT performance is negative, the weakening procedure of the Am may not be required. In the present study, 2 patients with vertical muscle palsy with 40 PD exhibited negative results on FDT, and satisfactory corrections were achieved after partial transposition of the horizontal muscle. A positive outcome on FDT suggests the contracture of Am, and the need for Am recession prior to muscle transposition. In the present study, 29 (93.55%) eyes had positive FDT, and all these underwent Am recession in combination with the PRT procedure. Residual deviations were observed in 3 eyes, and additional recession of the Ym was performed. Through these procedures, the deviation of strabismus could be successfully corrected from up to 140 PD to orthotropia. Therefore, patients with acquired paralytic strabismus were suggested to promptly undergo surgical treatment if the clinical symptoms persisted after 6mo of conservative treatment. In addition, 2 patients with mild overcorrection of the lateral rectus palsy exhibited recovery to orthotropia during the follow-up period. This finding suggests that for patients with lateral rectus palsy, mild overcorrection facilitates better recovery over time. As this was a retrospective observational study, it had several limitations. In a future study, the sample pool should be expanded and the follow-up duration should be prolonged. Moreover, the factors having an impact on the amount of recovery and quantitative optimization of surgery design should be further studied.

In conclusion, the prognosis of different patients with paralytic strabismus varies with the etiologies—some may achieve favorable prognosis through conservative treatment, whereas others require surgery. In addition to course extension, secondary changes such as Am contracture will increase the difficulty of the operation and may affect the efficacy of the surgery. Therefore, patients who are indicated to undergo surgery after 6mo of conservative therapy should undergo the operation as soon as possible. When an operation is scheduled, the residual function of the palsy-affected muscles should be first evaluated to choose a suitable surgery procedure. For complete paralytic strabismus due to single rectus muscle palsy, the PRT can effectively correct ocular alignment in the primary position, improve ocular motility, and eliminate diplopia and the compensatory head position. However, additional details should be carefully considered during the operation to achieve a satisfactory outcome. FDT should be conducted preoperatively and intraoperatively, and the ciliary blood vessels should be carefully preserved during muscle separation. Moreover, a symmetric transposition is a better choice to avoid new-onset deviations.

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