Surgical Outcomes Following Rectus Muscle Plication: A Potentially Reversible, Vessel-Sparing Alternative to Resection

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**IMPORTANCE** Extraocular muscle strengthening is a common treatment for strabismus. Plication is an alternative procedure for strengthening muscles with less tissue trauma than resection.

**OBJECTIVE** To compare the surgical dose effect of plication with that of resection.

**DESIGN, SETTING, AND PARTICIPANTS** Retrospective comparison of surgical outcomes in an academic pediatric ophthalmology and strabismus practice from July 25, 2005, through March 28, 2013, with a mean follow-up of 137 days for plication and 1243 days for resection. A single surgeon performed all procedures. Twenty-two consecutive patients underwent bilateral horizontal rectus plication or plication combined with antagonist recession (13 with esotropia and 9 with exotropia; mean [SD] age, 38 [21] years). Thirty-one consecutive patients underwent bilateral resection or resection combined with antagonist recession (12 with esotropia and 19 with exotropia; mean [SD] age, 28 [24] years). Six patients underwent vertical rectus plication.

**EXPOSURES** Rectus resection or plication performed by folding the anterior tendon posteriorly under the muscle margins oversewn to the poles of the scleral insertion, avoiding the anterior ciliary arteries.

**MAIN OUTCOMES AND MEASURES** Postoperative binocular alignment at the first postoperative and last available examinations.

**RESULTS** Lateral rectus plication (mean [SD], 6.5 [2.2] mm) and resection (6.6 [1.6] mm) were performed for similar magnitudes of esotropia (27.9 [13.4] prism diopters [PD] for plication, 29.0 [15.2] PD for resection; P = .44). Mean (SD) initial correction by lateral rectus plication was 5.17 (0.29) PD/mm, slightly less than the 95% CI (5.51-7.75 PD/mm) for resection (6.63 [0.50] PD/mm). Medial rectus plication (mean [SD], 4.9 [0.9] mm) vs resection (5.1 [1.1] mm) was performed for similar magnitudes of exotropia (32.8 [14.2] PD for plication, 31.2 [15.6] PD for resection; P = .33). Mean (SD) initial correction by medial rectus plication (7.10 [1.65] PD/mm) was within the 95% CI (4.65-9.87 PD/mm) for resection (7.26 [1.23] PD/mm). Initial and late effects were similar. Ciliary circulation observed at surgery remained patent after plication. Plication was cosmetically acceptable and did not produce conspicuous tissue elevations.

**CONCLUSIONS AND RELEVANCE** Horizontal rectus muscle plication is a rapidly performed, technically simple surgical procedure to strengthen the rectus muscles, with an equivalent (per millimeter) in surgical effect to that of medial rectus resection for treatment of esotropia and exotropia. Plication diminishes surgical trauma and does not intentionally sacrifice ciliary circulation, with the potential for reversal by suture release in the first postoperative days.


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Resection, the historically preferred extraocular muscle-strengthening procedure, has the disadvantage of irreversible removal of tendon. Plication is considered as an alternative by some strabismologists for strengthening of the horizontal rectus muscles. Although resection typically involves deliberate severing and removal of ciliary vessels, animal studies have demonstrated preservation of ciliary circulation after rectus plication, an advantage permitting more than 2 rectus muscles to undergo operative repair simultaneously in a single eye without fear of anterior segment ischemia.

Classic rectus muscle-to-muscle plication (tucking), as performed for the superior oblique muscle, was supposed to produce unaesthetic rectus muscle tissue overlap visible transconjunctivally. Muscle-to-sclera plication, however, reportedly does not leave conspicuous tissue. Vertical rectus muscle plication is claimed to have good results.

In light of the advantages of muscle-to-sclera plication, this study aimed to compare its effect with that of resection. We hypothesized that the dose effect of plication would be similar to that of resection, as indicated by the tables published by Parks et al. Limited results of vertical rectus plication are also described.

Methods

With institutional review board approval and waiver of informed consent, we performed a retrospective analysis of consecutive patients who underwent muscle plication and resection by a single surgeon (J.L.D.) from July 25, 2005, through March 28, 2013, at the Jules Stein Eye Institute. Patients underwent complete ophthalmic clinical examination, including distance and near heterotropia by prism and cover testing, clinical ocular motility evaluation, Hess screen testing, and assessment of stereopsis using the Titmus fly test.

We excluded patients undergoing surgery on muscles previously treated by operative procedures. Prior surgery on other muscles not currently undergoing surgery was not an exclusion criterion. Surgical doses for plication and resection were as recommended for resection by Parks et al. Because surgical preference changed in 2011, patients who had concomitant horizontal strabismus underwent plication in lieu of resection. The extent of recession of the antagonist muscle or plication or resection of the same muscle in the contralateral eye was as recommended by Parks et al. Operations were performed under general anesthesia using a limbal-conjunctival incision or the Swan incision over the insertion. The plicated muscle was hooked and connective tissues were gently retroplaced with cotton tip applicators. As illustrated in Figure 1 and the Video, a double-

Figure 1. Sequential Surgical Steps of Plication

A. Passage of sutures through the muscle margins at a distance equal to that for resection. B. Passage of scleral sutures on both sides of the insertion. C and D. Folding of the muscle over a temporarily placed iris sweep so that the anterior tendon folds posteriorly against the globe. E. Plicated muscle demonstrates no prominence. F. Conjunctival closure is completed with minimal distortion.
armed polyglactin suture (Vicryl 6-0; Ethicon) was bisected and each end passed through a muscle margin at the distance from the scleral insertion corresponding to the plication amount. The 2 sutures were then each passed through the partial thickness of the sclera adjacent to the corresponding pole of the insertion. An iris sweep was placed temporarily between the tendon and the sutures, forming a fulcrum over which the anterior tendon was folded flat between the muscle and globe. The conjunctiva was then closed with a second polyglactin suture (Vicryl 9-0; Ethicon) (Figure 1). A standard muscle resection procedure was used. An antibiotic and corticosteroid ointment was administered daily postoperatively for 1 week. Ciliary circulation observed at surgery remained preserved after plication.

Postoperative alignment was recorded at the first and the most recent postoperative examinations. Alignment effects were plotted against surgical doses to derive response graphs for plication comparable to the resection dose according to Parks et al.1

Nonabsorbable sutures (5-0 polyester; Ethicon) were used in 2 additional cases. One case involved 10-mm inferior rectus (IR) plication in a patient with thyroid eye disease and ocular myasthenia gravis who had hypertropia of 90 prism diopters (PD) despite prior 10-mm superior rectus recession and 7-mm contralateral IR recession. In the second case, a slipped medial rectus (MR) was resected and sutured at the sclera by an adjustable technique. In addition, the resected MR was advanced 2 mm and plicated to the sclera. Because plication cannot be adjusted by further advancement, this plication augmentation was intended to provide an increment in correction that could be released in the event of overcorrection. If weakening were required, the muscle could have been allowed to recess as in a standard adjustable resection surgery.22-23

Four other patients with hypertropia underwent IR plication. In an additional patient with infraversion palsy, bilateral IR plication was combined with bilateral superior rectus recession to shift a nystagmus null upward to correct ocular torticollis.16 The postoperative appearance of plicated lateral rectus (LR) muscles was clinically photographed in a young female patient after collection of the dose-response data for this study (Figure 2).

Regression analysis of surgical dosage in millimeters per PD of distance deviation corrected was calculated using commercially available statistical software (GraphPad Prism; GraphPad Software, Inc) and compared with the data of Parks et al.1 When both eyes underwent surgery, the target angle was assumed to be divided equally between eyes. When recession and antagonist shortening by plication or resection were performed concurrently in the same eye, the effect of shortening was computed in context of the corresponding amount of recession in the data of Parks et al.1 Unless otherwise specified, data are expressed as mean (SD).

Results

A total of 22 patients (17 male and 5 female; mean [SD] age, 38 [21] years) underwent bilateral plication or plication and antagonist recession. A total of 31 patients (14 male and 17 female; mean [SD] age, 28 [24] years) underwent bilateral muscle resection or unilateral resection and antagonist recession for the planned target angle as determined by the tables of Parks et al.1

Medial Rectus Plication for Exotropia

Mean exotropia of 30.6 (10.7) PD was present in 9 patients (8 male and 1 female) undergoing MR plication. Surgery was primary in 7 patients and a second procedure on other muscles in 2. Mean MR plication was 4.9 (0.9) mm when performed bilaterally and when unilaterally accompanied by mean LR recession of 6.4 (1.4) mm. Surgery reduced mean preoperative exotropia to 0.9 (2.7) PD in the immediate postoperative period and to 1.6 (3.1) PD at a mean follow-up of 146 (119) days (Table). Postoperative stereopsis of 1 patient improved to 40 arcseconds from a preoperative measurement of 100 arcseconds. Five more patients with preoperative stereopsis demonstrated postoperative stereopsis of 40 to 3000 arcseconds.

Medial Rectus Resection for Exotropia

Mean preoperative exotropia of 31.2 (15.6) PD was present in 19 patients (8 male and 11 female) undergoing MR resection. Surgery was primary in 16 patients and with previous surgery performed on other muscles in 3 (Table). Mean MR resection of 5.1 (1.1) mm was performed concurrently with mean LR recession of 6.7 (1.4) mm, reducing mean exotropia to 1.2 (2.2) PD in the immediate postoperative period and 2.2 (3.6) PD at a mean follow-up of 966 (1120) days. Four of 19 patients had stereopsis of 40 arcseconds preoperatively and postoperatively. Three other patients without preoperative stereopsis had mean postoperative stereopsis of 183 (189) arcseconds.

Comparison of Medial Rectus Plication vs Recession for Exotropia

Because surgical effects were reasonably linear, linear regressions are plotted in Figure 3, along with expected effects according to the tables of Parks et al1 for resection. Immediate mean postoperative exotropia correction of 7.11 (1.18) PD/mm for MR resection was nearly identical to 7.04 (1.57) PD/mm for plication, and plication effect was within the 95% CI of 4.65-9.87 PD/mm for resection. Although the observed effects of plication and resection were nearly identical, effects of both were significantly (P < .05) less than the mean linear effect of resection of 10.34 (1.03) PD/mm according to Parks et al.1 This effect implies that MR plication has an effect equivalent to that of resection, but effects of both are about 30% less than anticipated from linear regression of the recommendations of Parks et al.1 However, Parks et al predict nonlinear effects (Figure 3). Although the coefficient of determination for a linear fit to Parks et al is $R^2 = 0.79$, a quadratic fit has a coefficient of determination of $R^2 = 0.93$. A nonlinear fit thus accounts for 93% of variance in effect, whereas a linear fit accounts for only 79%. As seen from Figure 3, a linear fit to the tables of Parks et al overestimates surgical effect at doses of less than 4 mm, is accurate in the range of 4 to 7 mm that is typical of most surgical procedures, and overestimates the effect for resection exceeding 7 mm. Consequently, for surgical procedures treating the typical clinical range of exotropia of 20 to 50 PD, plication and resection have similar effects predictable from the tables of Parks et al.1

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Similar analysis was performed using the last available follow-up data obtained at a mean of 146 (119) postoperative days for MR plication and 966 (1120) postoperative days for MR resection. For exotropia, the mean effect of MR plication increased insignificantly from 7.10 (1.65) PD/mm initially to 8.08 (1.63) PD/mm at last follow-up ($P > .05$). The mean effect of MR resection decreased insignificantly from 7.26 (1.23) PD/mm initially to 6.81 (1.58) PD/mm at last follow-up ($P > .05$). After long-

![Figure 2. Anterior Segment Appearance After Plication](image)

Table. Effect of Plication and Resection on Binocular Alignment

<table>
<thead>
<tr>
<th>Surgery</th>
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<td></td>
<td>Preoperative Deviation, PD</td>
<td>MR Surgery, mm (Procedure)</td>
<td>LR Surgery, mm (Procedure)</td>
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<td>Resection</td>
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<td>Exotropia (n = 19)</td>
<td>31.2 (15.6)</td>
<td>5.1 (1.1) [Recession]</td>
<td>6.7 (1.4) [Recession]</td>
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<tr>
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<td>29.0 (15.2)</td>
<td>5.2 (1.4) [Recession]</td>
<td>6.6 (1.6) [Recession]</td>
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<td>Plication</td>
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<tr>
<td>Exotropia (n = 9)</td>
<td>32.8 (14.4)</td>
<td>4.9 (0.9) [Plication]</td>
<td>6.4 (1.4) [Recession]</td>
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<tr>
<td>Esotropia (n = 13)</td>
<td>27.9 (13.4)</td>
<td>4.7 (1.4) [Recession]</td>
<td>6.5 (2.2) [Plication]</td>
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Abbreviations: LR, lateral rectus; MR, medial rectus; PD, prism diopter.
Lateral Rectus Plication for Esotropia

Mean esotropia of 27.9 (13.4) PD was present in 13 patients (9 male and 4 female). Surgery was primary in 9 patients and a second procedure for muscles other than the LR undergoing surgery in 3 cases. Mean LR plication was 6.5 (2.2) mm when performed bilaterally; mean MR recession was 4.7 (1.4) mm when performed unilaterally. This surgery reduced mean esotropia to 0.6 (2.2) PD immediately after surgery and to 1.8 (3.8) PD during a mean follow-up of 130 (155) days. Mean postoperative stereopsis of the 3 patients who demonstrated it preoperatively improved from 233 (153 [range, 40-200]) arcseconds to 80 (35) arcseconds (P = .08). Two patients without preoperative stereopsis demonstrated individual postoperative stereopsis of 3000 and 100 arcseconds.

In an additional case not included in statistical analysis, an MR that had slipped as a result of surgery 30 years before was resected, advanced 2 mm, plicated, and secured by adjustable technique. Because plication cannot be adjusted by further advancement, this additional augmentation was intended to provide a potentially releasable increment in correction in event of overcorrection. When overcorrection occurred, the plication was released by suture removal 48 hours after surgery with alignment improvement. Because the plicated muscle underwent a second operation, this case was not included in the dose-response calculation.

Regressions for plication (9 patients) are compared with resection (19 patients) and the effect of resection predicted by Parks et al. Some symbols overlap. Linear regression for plication, Effect = 7.26 × Surgical Dose − 9.36 (R² = 0.69). Linear regression for resection, Effect = 711 × Surgical Dose − 9.36 (R² = 0.69). Linear regression for Parks et al, Effect = 10.34 × Surgical Dose − 23.73 (R² = 0.79). The 95% confidence intervals for regression slopes are provided. Quadratic fit to the data of Parks et al, Effect = 57.04 − 21.43 × Surgical Dose − 23.73. Surgical dose is given in millimeters. The quadratic form fits the recommendations of Parks et al better than a linear equation. PD indicates prism diopters.

For plication, Effect = 6.63 × Surgical Dose − 13.80 (R² = 0.98). For resection, Effect = 6.63 × Surgical Dose − 13.80 (R² = 0.95). For Parks et al, Effect = 5.56 × Surgical Dose − 7.28 (R² = 0.98). The 95% confidence intervals for regression slopes are provided. PD indicates prism diopters.

Comparison of Lateral Rectus Plication vs Resection for Esotropia

A mean LR plication of 6.5 (2.2) mm was performed, nearly identical to resection of 6.6 (1.6) mm for similar mean magnitudes of esotropia (27.9 [13.4] PD for plication, 29.0 [15.2] for resection; P = .44). Because responses for plication and resection were reasonably linear, early outcome data were analyzed by linear regression, showing a mean correction of esotropia by LR plication of 5.17 (0.29) PD/mm, significantly lower than the 6.63 (0.50) PD/mm for resection. The slope for plication was below the 95% CI of 5.51 to 7.75 PD/mm for resection (Figure 4). Coefficients of determination for linear regressions were R² = 0.97 for plication and R² = 0.95 for resection, confirming that surgical responses were linear and that doses accounted for nearly all variance. Effects predicted from the tables of Parks et al were also highly linear, with a coefficient of determination of R² = 0.98 for linear and quadratic regressions. Parks et al predicted a mean corrected effect of 5.56 (0.19) PD/mm, which is within the 95% confidence interval for plication (4.61-5.67). Therefore, although Parks et al reasonably predicted early effects of plication and resection, their tables slightly overestimate the for-

Lateral Rectus Resection for Esotropia

Mean LR resection of 6.6 (1.6) mm was performed concurrently with mean MR recession of 5.2 (1.4) mm in 12 patients (6 male and 6 female), reducing mean esotropia from a preoperative value of 28.6 (14.5) PD to 0.5 (1.2) PD in the immediate postoperative period and to 2.0 (2.6) PD at a mean follow-up of 1682 (2124) days. One patient with preoperative stereopsis of 3000 arcseconds experienced improvement to 200 arcseconds. The other patient retained the same value postoperatively. Another patient without preoperative stereopsis demonstrated postoperative stereopsis of 3000 arcseconds.

Regressions for plication (13 patients) compared with resection (12 patients) and the effect of resection predicted by Parks et al. Some symbols overlap. For plication, Effect = 5.14 × Surgical Dose − 5.42 (R² = 0.97). For resection, Effect = 6.63 × Surgical Dose − 13.80 (R² = 0.95). For Parks et al, Effect = 5.56 × Surgical Dose − 7.28 (R² = 0.98). The 95% confidence intervals for regression slopes are provided. PD indicates prism diopters.

1. Parks et al
2. Linear fit
3. Quadratic fit
4. Some symbols overlap
5. Surgical Dose, mm
6. Surgical Effect, PD
7. Linear fit
8. Quadratic fit
9. Parent study from which data are derived
10. PD indicates prism diopters
Plication for Hypertropia

Six patients with hypertropia underwent IR plication. One patient had a traumatic IR flap tear managed by posterior scleral fixation. Another patient with infraversion palsy, bilateral IR plication was combined with bilateral superior rectus recession to shift a nystagmus null upward to correct ocular torticollis. One patient had Duane syndrome with limited abduction and adduction, and another had cerebellar ataxia and downbeat nystagmus. Nonabsorbable sutures (5-0 polyester; Ethicon) were used in a 20-mm IR plication in a patient with thyroid eye disease and ocular myasthenia gravis who had 90-PD hypertropia despite prior 10-mm superior rectus recession and 7-mm contralateral IR recession. One patient underwent IR plication for residual vertical deviation.

Paucity of cases made it impossible to analyze the dose response of the 6 patients who underwent IR plication. However, the patient with thyroid ophthalmopathy who underwent IR plication in the 90-PD hypertropic eye was orthophoric immediately after surgery, but by 8 postoperative months, the hypertropia partially recurred to 20 PD. The patient with trauma remained orthophoric after a follow-up of 7 months, as did the patient with infraversion palsy, in whom IR plication was performed in lieu of IR resection. Two other patients were orthophoric at last follow-up, whereas the third with Duane syndrome had later recurrence of ipsilateral hypertropia.

Postoperative Comfort and Appearance

Patients reported only minimal postoperative discomfort after plication and resection and did not complain of cosmesis. Plicated muscles were inconspicuous through the conjunctiva (Figure 1F and Figure 2). Postoperative appearance was not analyzed quantitatively in this study. However, Figure 2 illustrates the essentially normal appearance 8 months after 6.5-mm bilateral LR plication and 51 months after 5-mm bilateral MR recession in a young patient treated after completion of the dose-response study.

Discussion

Resection and plication have been considered effective for muscle strengthening. However, contemporary English literature has generally favored tendon-to-tendon plication for the superior oblique and resection for the rectus muscles as standard approaches to strengthening. Reasons for these choices are uncertain, but different approaches probably evolved in various parts of the world. We found a paucity of comparative studies for relative surgical advantages, and the available literature does not compare quantitative dose effects. The present study found that the effect of plication is similar to that of resection for the MR and LR.

Plausible advantages of rectus plication reportedly include simplicity; short operating time; less surgical trauma, inflammation, and hemorrhage; and early reversibility. These advantages are extended by the present study’s demonstration of response predictability and similarity to resection effect. Plication with minimal dissection, adapted to the small-incision technique, may offer further advantages.

Routine rectus muscle resection generally requires extirpation of segments of the anterior ciliary arteries, interrupting this source of circulation to the anterior eye. Animal studies have demonstrated that plication to the sclera preserves the ciliary blood flow of the muscle undergoing surgery. Placement of sutures at the muscle margins during plication averts ciliary vessel destruction. These studies suggest that plication is valuable in situations in which anterior segment ischemia is a consideration.

Another advantage is that plication can be performed readily under topical anesthesia because plication does not entail relatively painful muscle crushing. Although adjustable plication may be more difficult to perform because the muscle may unfold during suture relaxation, plication could be combined with adjustable resection in the fellow eye to augment the range of adjustability. Placement of a second temporary suture securing a plication of a modestly larger amount than estimated to be necessary can permit postoperative release in the event of excessive postoperative result. However, this adjustment strategy can only serve to decrease, not to increase further, the surgical effect.

Substitution of plication for resection in thyroid ophthalmopathy might decrease inflammation because plication is arguably less traumatic. Cautious resection has been suggested for treating large-angle strabismus in thyroid ophthalmopathy, especially reoperations. Plication was substituted for resection for management of a vertical nystagmus null point, for which it was effective in the present study.

The present data indicate that surgeons may regard plication as quantitatively equivalent to resection for horizontal rectus surgery. Plication and resection of the LR have highly similar, predictable, linear effects in treatment of esotropia. Perhaps owing to differing fundamental pathophysiological features, plication and resection of the MR have modestly less linear and predictable effects in the treatment of exotropia. The published tables of Parks et al. overestimate the effect of LR plication and underestimate the effect of LR resection. These differences from published recommendations are probably clinically negligible.
Conclusions

The convenience and predictable effectiveness of plication recommends its application in routine horizontal muscle surgery. In addition, plication is initially reversible, can be adapted for adjustment in combination with resection, and can be performed as a vessel-sparing procedure, thus increasing options for simultaneous operations of multiple rectus muscles.

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Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: All authors.
Critical revision of the manuscript for important intellectual content: All authors.
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