Innovative techniques for the treatment of adult strabismus

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SUMMARY   Adult strabismus is often characterized by surgical complexity. In recent years, several innovative techniques for the management of complex strabismus have been developed. Strabismus surgeons should understand the indications for various strabismus surgical techniques in the management of these difficult cases. This workshop describes several new surgical techniques to manage complex strabismus, including small-angle incomitant and very large-angle strabismus, torsional diplopia, and restrictive, paralytic, and secondary strabismus. Because strabismus surgery is an ever-evolving field, it is important to continue to refine our surgical armamentarium. Strabismus surgeons may wish to add these techniques to their surgical repertoire for select cases.   (J AAPOS 2019;23:132-139)

Adult strabismus is present in 4%, or approximately 10 million American adults annually, and the prevalence is increasing.[1] Given the increasing proportion of our elderly population, it is crucial to have a variety of tools to treat more complex cases of adult strabismus, which is in some respects more difficult to treat surgically than pediatric strabismus surgery. First, adults with strabismus often present with incomitant deviations that are commonly associated with diplopia. Second, adults more often present with very small symptomatic deviations. Lastly, torsional deviations are more commonly symptomatic in adults. Adults are more likely than children to suffer from intractable diplopia, even after mild overcorrections. This workshop discusses innovative techniques to aid surgeons who manage these very difficult patients. Our workshop describes five techniques, including those that address incomitance, including posterior fixation with adjustable recession (JMH) and adjustable small-incision

selective tenotomy and plication (MYC), and those that address very large deviations, including botulinum toxin as a replacement for traction sutures (SBÖ), and extraocular muscle transplantation (RK), and a new technique to address excyclodeviation, namely anterior superior oblique tuck (FGV).

Posterior Fixation with Adjustable Recession

When faced with incomitant strabismus, we would often like to recess a muscle to weaken the effect in straight-ahead gaze, titrating that effect on an adjustable suture, and provide posterior fixation behind the equator of the globe, to further weaken the effect of that muscle in its field of action.[2] Nevertheless, most surgical techniques allow either an adjustable recession of a rectus muscle or posterior fixation of a rectus muscle behind the equator, but not both in the same procedure. Combining an adjustable recession with posterior fixation allows fine-tuning of the deviation in straight-ahead gaze but also has the advantage of posterior fixation to further weaken the effect of the muscle in its field of action.

Although the resection-recession (Scott) procedure[3] on the same rectus muscle has been reported to achieve a similar effect to classic posterior fixation,[4-7] there are a number of concerns. The attachment point of the muscle (with the resection-recession procedure) often does not lie behind the equator of the globe or very far behind the equator of the globe and therefore is not consistent with one of the most widely proposed mechanisms of posterior fixation, namely, a progressively reduced lever arm[8]; moreover, when performing a hangback resection-recession procedure on adjustable sutures, there is a danger that the distal end of a medial or inferior rectus muscle may not contact the globe, due to the short arc of contact. Therefore, the distal end of the muscle may be suspended within the pulley rather than touching

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the globe, increasing the risk that the muscle will not adhere to the sclera.

Surgical Technique

The specific surgical technique has been previously described for the lateral rectus muscle,[9] but the technique has also been applied by the author (JMH) to the medial, inferior, and superior rectus muscles. The procedure is similar to a nonadjustable central posterior fixation suture technique described by Del Monte and Archer[10] and shares features of a technique mentioned by Kushner.[11] Briefly, the muscle is imbricated with a double-armed 6-0 polyglactin 910 suture and disinserted from the sclera. A 5-0 polyester suture is used for posterior fixation taking a 3 mm scleral bite, typically 14 mm posterior to the original insertion for a medial rectus muscle, 15 mm for an inferior rectus muscle, 17 mm for a superior rectus muscle, and 18 mm for a lateral rectus muscle. A 6-0 polyester suture was used originally,[9] but this became unavailable, and so a 5-0 suture is used on the same spatulated S-14 needle. Each needle of the 5-0 polyester is then passed through the belly of the muscle 1/4 to 1/3 muscle width from the edge of the muscle (Figure 1A). The distance from the distal end of the muscle should account for planned amount of initial recession. For example, an inferior rectus muscle, with a 15 mm posterior fixation suture and planned recession of 5 mm, the polyester sutures would be passed through the muscle 10 mm from the distal end of the muscle. The muscle is then reattached to the sclera using the 6-0 polyglactin 910 sutures taking scleral bites at the original insertion in a crossed swords fashion (Figure 1B). A sliding 6-0 polyglactin 910 noose is then tied around the sutures to set the desired amount of planned recession but allowing reduction or increase in the amount of recession at the time of adjustment. The 5-0 polyester posterior fixation suture is then tied over the belly of the muscle, opposing the muscle to the sclera but not so tight as to preclude adjustment of the recession should it be desired at the time of the adjustment (Figure 1B). The posterior fixation suture remains in place, attached to the sclera, and the muscle belly slides forward or backward if adjustment is performed. It is postulated the posterior fixation suture splits the muscle fibers along their natural cleavage lines, allowing the muscle belly to move while the posterior fixation suture remains in place. Although splitting of the muscle for a few millimeters may occur if the recession is adjusted, the central part of the muscle remains in apposition to the sclera, thereby retaining the posterior fixation effect. In the first few cases,[9] the polyester posterior fixation sutures were slid anterior-posterior to create two slits in the muscle parallel with the muscle fibers in order to allow the muscle to slide forward or backward at the time of adjustment, but this has subsequently been found not to be necessary. Anecdotally, up to 3 mm of adjustment has been found to be achievable with the described technique. Larger adjustments may be limited by increasing difficulty of the poly-
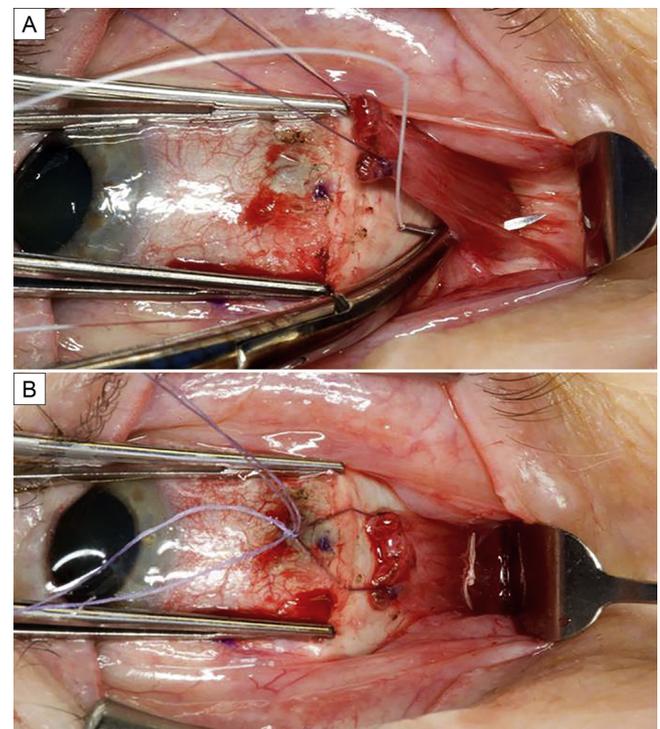
FIG 1. A, After imbricating and disinserting the rectus muscle, a 3 mm scleral bite is taken at the desired location of the posterior fixation suture (typically 14–18 mm from the insertion, depending on the specific muscle). One arm of the double-armed 5-0 polyester posterior fixation suture is then passed through the belly of the rectus muscle, approximately 1/4 muscle width from the edge of the muscle (shown); the second arm of the suture is similarly passed adjacent to the opposite edge. B, The muscle is reattached to the sclera with the 6-0 polyglactin 910 sutures and a 6-0 polyglactin 910 sliding noose is used to set the desired amount of initial recession (allowing adjustment of the recession later in the day). The 5-0 polyester posterior fixation suture is tied over the muscle belly to oppose the muscle to the sclera but not so tight as to preclude adjustment of the recession should it be deemed necessary.

ester suture, further splitting the muscle fibers using either the force generated by pulling the muscle (if advancing at adjustment) or the force generated by the muscle itself (if re-recessing at adjustment). Although advancement and further recession are achievable at the time of adjustment, anecdotally it seems slightly easier to advance the muscle than to further recess it. Having said that, rather than over-recess every muscle with plans to advance at adjustment, it seems most reasonable to set the muscle at the predicted best position, expecting many to be simply tie-off at adjustment.

An alternative surgical technique to allow adjustable recession along with posterior fixation is the "muscle strapping technique" of Quéré and colleagues,[12] but we have less experience with this technique. Another alternative technique is untying and retying the posterior fixation sutures at the time of adjustment, as described by Hoover[13] for the inferior rectus muscle, but it is unclear whether

this is feasible for the other rectus muscles and whether the majority of patients would tolerate that type of adjustment.

Adjustable Small-incision Selective Tenotomy and Plication for Correction of Horizontally Incomitant Vertical Strabismus

Incomitant vertical strabismus is challenging to treat surgically. Because such cases are often complicated and require operation on multiple rectus muscles, a technique that allows ciliary vessel sparing is desirable. We describe two procedures to provide relative preservation of ciliary vessels while treating small-angle cyclovertical strabismus: selective tenotomy and plication of vertical rectus muscles.[14] In these techniques, surgery is performed on the nasal or temporal fibers of the vertical rectus muscles for correction of horizontally incomitant vertical strabismus. The physiological basis of selective extraocular muscle surgery may relate to compartmental innervation of some extraocular muscles, as described by Demer and colleagues.[15]

Surgical Technique

Figure 2 demonstrates the algorithm for determining which muscle to choose for selective tenotomy or plication, based on direction of incomitance. If a patient has cyclotorsion, we preferentially select a procedure that will improve the cyclodeviation. Figure 3 illustrates the surgical steps for selective tenotomy of a vertical rectus muscle. The vertical rectus muscle is isolated on a Jameson hook. The nasal or temporal half of the muscle is secured with a 6-0 polyglactin 910 suture just posterior to the insertion, and 50% of the nasal or temporal fibers are disinserted with Westcott scissors. The suture is passed at the original insertion and tied in an adjustable slipknot. Because the central part of the tendon is still attached at the original insertion, hanging back one pole of the muscle results in a diagonal configuration of the new muscle insertion (Figure 3) rather than a straight horizontal insertion as described by Archer and colleagues[16] after an 80% tenotomy secured by nonadjustable sutures. Tenotomy is performed on only 50% of the tendon, because the procedure aims to correct horizontal incomitance of a vertical deviation rather than eliminate a hypertropia, which would typically require a larger partial tenotomy.[16] For selective plication, the surgical steps are the same, except that the nasal or temporal half of the muscle is secured with a suture posterior to the insertion at a distance equal to the desired amount of plication and no tenotomy is performed. We typically perform adjustment in the postoperative recovery area on the day of surgery.

We have previously published our experience with selective tenotomy and plication of vertical rectus muscles for correction of horizontally incomitant vertical strabismus and cyclodeviation.[14] That study included 9 patients: 4 underwent selective plication, and 5 underwent selective tenotomies. Preoperatively, the average horizontal incomitance (vertical deviation difference between left
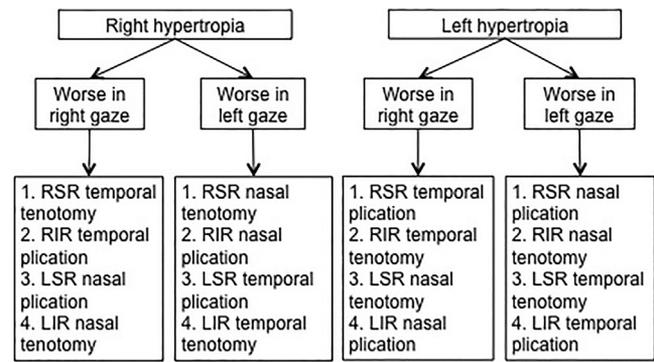

FIG 2. Flowchart for surgical planning of selective tenotomy or plication in patients primarily symptomatic from horizontally incomitant vertical strabismus. *LIR*, left inferior rectus muscle; *LSR*, left superior rectus muscle; *RIR*, right inferior rectus muscle; *RSR*, right superior rectus muscle.

and right gazes) was 6.2^{Δ} (range, 3^{Δ}-14^{Δ}). Eight patients had preoperative cyclodeviation with an average torsion measurement of 7.6° (range, 5°-10°). We calculated the percentage of patients with successful postoperative correction of horizontally incomitant vertical strabismus (defined as hypertropia less than 4^{Δ} in primary, lateral, and down gaze positions with an absence of diplopia) and cyclodeviation (defined as <5° of torsion by double Maddox rod testing with absence of diplopia). Overall, surgery was successful in correcting horizontally incomitant vertical strabismus in 8 patients. Cyclodeviation was successfully treated in 4 of 8 patients. Diplopia resolved in 8 of 9 patients. We found that patients who did not achieve successful correction of cyclodeviation were more likely to have undergone prior strabismus surgeries or orbital disease. These factors may contribute to scar tissue formation and decrease likelihood of affecting torsion. Moreover, the relatively small partial tenotomy (50%) may account for the minimal effect on torsion. Because the effect on cyclotorsion was unpredictable, we now mainly use this procedure to correct incomitant vertical strabismus. Compared to other surgeries for cyclovertical strabismus,[17,18] selective tenotomy and plication have potential advantages, including use of adjustable sutures and relative sparing of ciliary circulation, because only one of two ciliary arteries per rectus muscle are expected to be affected. Additionally, the procedures may be performed under topical anesthesia in some cases. We encourage strabismus surgeons to consider selective tenotomy and plication of vertical rectus muscles for treatment of cyclovertical strabismus, particularly horizontally incomitant vertical deviations.

Botulinum Toxin as a Replacement for Traction Sutures

In chronic paralytic motility disorders, major challenges to surgical correction include the severe contracture of the
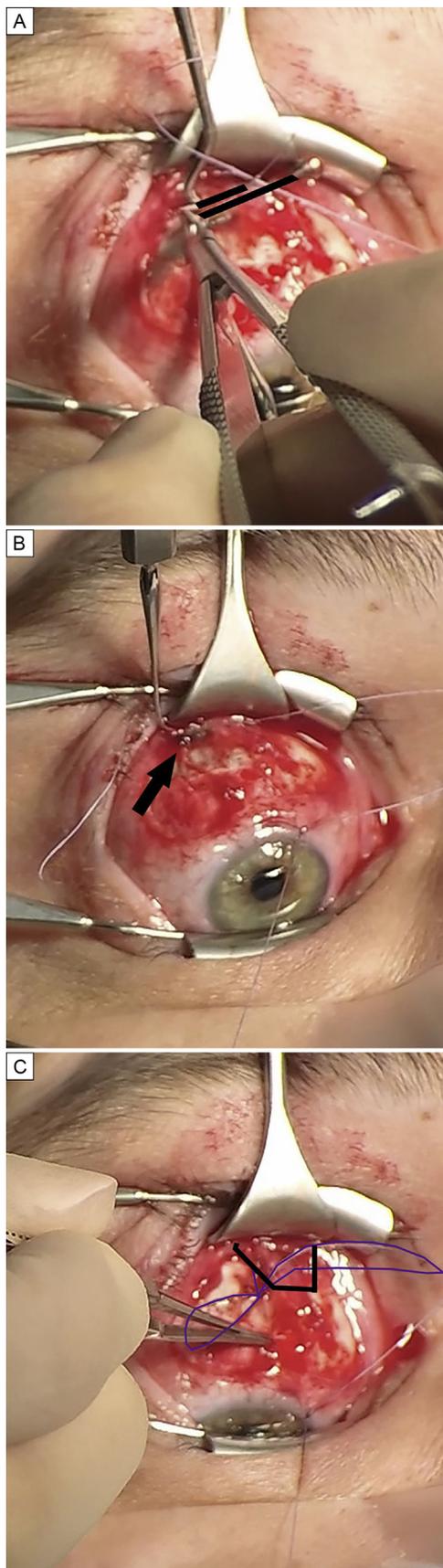
FIG 3. Surgical steps for selective tenotomy of right superior rectus. A, The superior rectus muscle is isolated with a Jameson hook. A

unopposed antagonist extraocular muscle and orbital fibrosis with shortening of the surrounding soft tissues. Similar problems may occur in patients with lost muscles and some types of restrictive motility disorders. To overcome this problem, traction sutures are often used to keep the eye in an overcorrected position. The traction sutures involve scleral bites at the muscle insertion site and come out through the upper and lower eyelids; they are to be kept in place for 6 weeks.[19]

It is known that botulinum toxin A (BTXA) injection produces a paralytic effect in the injected muscle. If a full paralytic effect could be obtained, a complete limitation of ocular motility in the direction of action of the injected muscle is expected to develop. For patients with longstanding paralytic strabismus, we currently use BTXA injection in combination with recession as a replacement for traction sutures, thereby providing early overcorrection to overcome the contracture of the antagonist extraocular muscle and orbital fibrosis.

Surgical Technique

In cases of longstanding severe paralytic strabismus with a secondary restrictive component and positive forced duction testing, typical recession and resection procedures are performed. Conjunctival recession may be added if indicated. In the recessed muscle, which typically undergoes very large recession, 10 units of BTXA is also injected at the time of surgery.

In our experience, patients typically have an overcorrection during the first postoperative week and occasionally experience ptosis if the BTXA affects the levator palpebrae superioris. However, in the long term (8-24 months postoperatively), patients that have undergone procedures using BTXA instead of traction sutures have had satisfactory results in primary position and have improved ocular ductions (Figure 4). We have previously demonstrated that soft tissue healing in a given eye position induced by BTXA injection provided a long-term effect similar to the traction sutures.[20] This could also be one of the explanations for the effect of BTXA in combination with recession-resect surgery.[21,22] Similarly, Kim and colleagues[23] used BTXA in combination with recession-resection surgery and obtained satisfactory results in 5 patients with oculomotor nerve palsy, but they did not comment on the overcorrection period or the presence of orbital fibrosis.

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single-armed 6-0 polyglactin 910 suture is passed through the temporal half of the muscle, just posterior to the insertion. The long black bar marks the length of the muscle insertion; the short black bar, the length of muscle secured by the suture. B, The temporal half of the insertion is cauterized (arrow) and disinserted using Westcott scissors. C, The suture is passed at the original insertion and tied in an adjustable slipknot for later adjustment (muscle borders outlined in black).

FIG 4. A 37-year-old woman who had suffered intracranial hemorrhage as a result of a traffic accident 15 months before surgery and presented with exotropia of 75$^\Delta$ and intractable diplopia. A, Preoperatively, there was severe limitation of adduction, depression, and elevation as −4 on a scale of 0 to 4. B, During surgery, forced duction test was +3 positive on adduction on a scale of 0 to 4 (+4 representing severe limitation). When forced duction was repeated after lateral rectus disinsertion, it was still +2 positive, suggesting orbital fibrosis. Very large recession of 12 mm was performed into the lateral rectus muscle in combination with 10 units of BTXA injection during the operation. The conjunctiva was also recessed for 6 mm. A large resection of 10 mm to the medial rectus muscle was also performed. Ten days after surgery she had an esotropia of 18$^\Delta$, with −3 limitation of abduction and −2 limitation of adduction. The overcorrected period lasted for 1 month. C, Two years later, she was orthophoric in primary position, with −2 limitation of both abduction and adduction.

Resections of completely paralytic extraocular muscles do not typically have a long-term effect, but our cases have suggested that large resections of completely paralytic extraocular muscles may provide a mechanical long-term effect if the eye remained in an overcorrected position during wound healing. The soft tissues surrounding the extraocular muscles may play role in this long-term effect. Similar to traction sutures, it is difficult to quantify how much the BTXA injection contributes to the final alignment, because these cases typically undergo supramaximal recession-resection procedures, and the amount of overcorrection may be variable. However, it is also known that in the presence of orbital fibrosis, where forced duction testing is still positive after severing the extraocular muscle, the effect of supramaximal surgery does not last long; this is an indication for the use of traction sutures.

There are several disadvantages to using BTXA in combination with recession as a replacement for tractions sutures, including risk of transient ptosis, which may be amblyogenic for the pediatric age group, inability to use hang-back sutures in large recessions, and the period of overcorrection, which is desirable but difficult for some patients to tolerate. If BTXA injection is to be performed in combination with recession, the extraocular muscle should be sutured to the sclera to minimize the risk of its migrating anteriorly, which may be challenging in very large recessions.[24]

Overall, our results suggest that BTXA is an effective alternative to traction sutures. The technique is easy to perform, well tolerated in all age groups, and does not

Table 1. Guidelines for the surgical dosage for transplantation of extraocular muscles

Esotropia, PD	LR resection	MR recession	Transplantation
60	8	5.5	3
70	8	6	4
80	8	6.5	5
90	9	6.5	6
Exotropia, PD	MR resection	LR recession	Transplantation
60	6	7	3
70	7	8	4
80	8	9	5
90	8.5	10	6

LR, lateral rectus; *MR*, medial rectus, *PD*, prism diopter.

have potential side effects of tractions sutures such as infections, corneal exposure, and early tearing out of the sclera due to erosion.
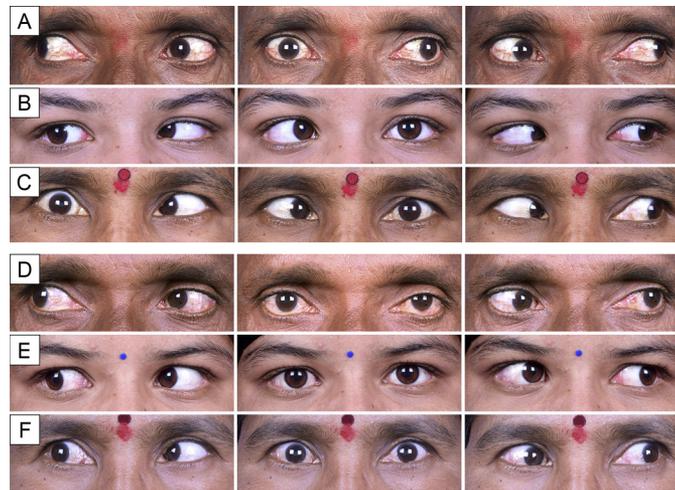
Extraocular Muscle Transplantation for Large-angle Strabismus

When there is an extra-large-angle strabismus, conventional muscle recession and resection procedures in one eye may not suffice. Hence very large muscle recession and resection, combining muscle recession with central tenotomy[25] or botulinum toxin augmentation,[26] medial rectus elongation,[27] Z tenotomy, and so forth, have been attempted in the strabismic eye with satisfactory outcomes.

The above situation becomes more challenging when it is associated with amblyopia, and the patient wants surgery only in the amblyopic eye. In the past, surgeons have attempted to elongate the muscle with vein, fascia lata, or silicone rods/sheets. All of these have their own limitations, especially with regard to long-term outcomes. In 1973 Hiatt[28] attempted muscle transplantation in dogs and human beings, reporting good outcomes. Since then Diamond, Amitava, and Jethani have performed these procedures in many patients of large-angle esotropia.[29-31]

Surgical Technique

For a case of esotropia, following an inferotemporal fornix incision, the lateral rectus muscle is hooked with a muscle hook. Double armed 6-0 polyglactin 910 suture is passed at the desired distance from its insertion as planned for the resection. One more double-armed 6-0 polyglactin 910 suture is passed through its insertion. The portion of the muscle is resected (typically 3−6 mm), and the remaining lateral rectus muscle is anchored back to the sclera at its insertion. The resected portion of the lateral rectus is kept aside in saline. The medial rectus muscle is then hooked through an inferonasal fornix incision. A 6-0 polypropylene nonabsorble suture is passed through its insertion. The medial rectus muscle is then disinserted. The distal end of the resected lateral rectus muscle is sutured to medial rectus muscle and secured. The proximal end of the lateral rectus muscle is then anchored to the sclera at the point in which the recession was planned (Table 1). The conjunctiva is closed on both

FIG 5. Patients undergoing extraocular muscle transplantation. A, Patient with exotropia of 75$^\Delta$ underwent lateral recession of 8.5 mm transplantation (4 mm) and medial rectus resection of 7 mm. B, Patient with esotropia of 75$^\Delta$ with dense amblyopia in the right eye underwent lateral rectus resection (8.5 mm) and medial rectus recession (6) with LR transplantation (4 m). C, Patient with partially resolved sixth nerve palsy having esotropia of 70$^\Delta$ in the primary position. She underwent lateral rectus resection (8 mm) and medial rectus recession (6 mm) with transplantation (5 mm) was performed. D, Postoperative patient depicted in Panel A after undergoing extraocular muscle transplantation. At 6 months' follow-up, he had exotropia of 8$^\Delta$ with good ocular motility. E, Postoperative patient depicted in Panel B after undergoing extraocular muscle transplantation. At 8 months follow-up, she had good alignment with normal ocular motility. F, Postoperative patient depicted in Panel C. Six months after the surgery, she was diplopia-free in the primary gaze and had good alignment in the primary position. But note the mild adduction limitation and improved abduction in the right eye.

sides using fibrin glue. The similar technique is followed for extra-large-angle exotropia, the procedure being medial rectus muscle resection and lateral rectus muscle recession with transplantation (See Video 1, available at jaapos.org).

In our experience, muscle transplantation with recession and resection of medial or lateral rectus muscle works very well for large-angle esotropia (>70$^\Delta$), large exotropia, and abducens nerve palsy with good abduction (Figure 5). Surgery on the dominant eye can be avoided in these situations. In addition, there is an advantage of better preservation of the ductions, as opposed to supra-large muscle recession. Jethani and colleagues[32] reported the long-term outcomes of muscle transplantation in 22 patients. All of the patients had esotropia of >85$^\Delta$ and a mean follow-up period of 2 years. All subjects had desirable outcomes with good abduction and a mean of −1 adduction limitation. Our results suggest that 1 mm of "alteration" (transplantation of resected medial or lateral rectus muscle) corrects up to 4$^\Delta$-5$^\Delta$ of strabismus. In addition, this procedure has been attempted with good outcomes for myopic strabismus fixus as well.[31] Figure 6 shows the pre- and postoperative images of 3 cases of extra-large-angle esotropia, exotropia, and incomitant esotropia, respectively. Hiatt[28] reported that transplanted muscle undergoes various changes. At the end of 28 days, various phases of necrosis and replacement by fibrous tissue with obliteration of the capillaries in the transplanted muscle is complete. Therefore, the transplant acts as a spacer with fibrous tissue without significantly affecting motility. It is currently un-

clear whether alternative spacers would have advantages or disadvantages compared with the patient's own muscle.

Anterior Superior Oblique Tuck

Excyclotropia is the anomalous temporal rotation of the eye around the Y-axis.[33,34] Cyclotropia is frequently seen in subjects with vertical strabismus due to malfunction of any of the cyclovertical muscles due to various etiologies.[33] Several procedures have been described to decrease excyclodeviation, including transposition of the vertical and horizontal rectus muscles, weakening of the inferior oblique muscle, and strengthening the superior oblique. In 1964 Harada and Ito[17] described the anteriorization of the anterior half of the superior oblique tendon to correct excyclotropia. This procedure is indicated in patients with symptomatic torsional diplopia due to excyclodeviation in whom a selective strengthening of the superior oblique incyclodeviational fibers is desired. The Fells modification of the Harada-Ito technique was introduced in 1974.[17,35] However, there are risks related to the Harada-Ito procedure, which may include unexpected induced vertical and horizontal deviations, unintended transection of the superior oblique tendon during the transposition of the anterior segment, and challenges to reinserting the tendon on the thinner posterior sclera.[17,18,36-41] In addition, in the absence of a significant vertical deviation, many of these procedures carry the risk of inducing a new vertical deviation.
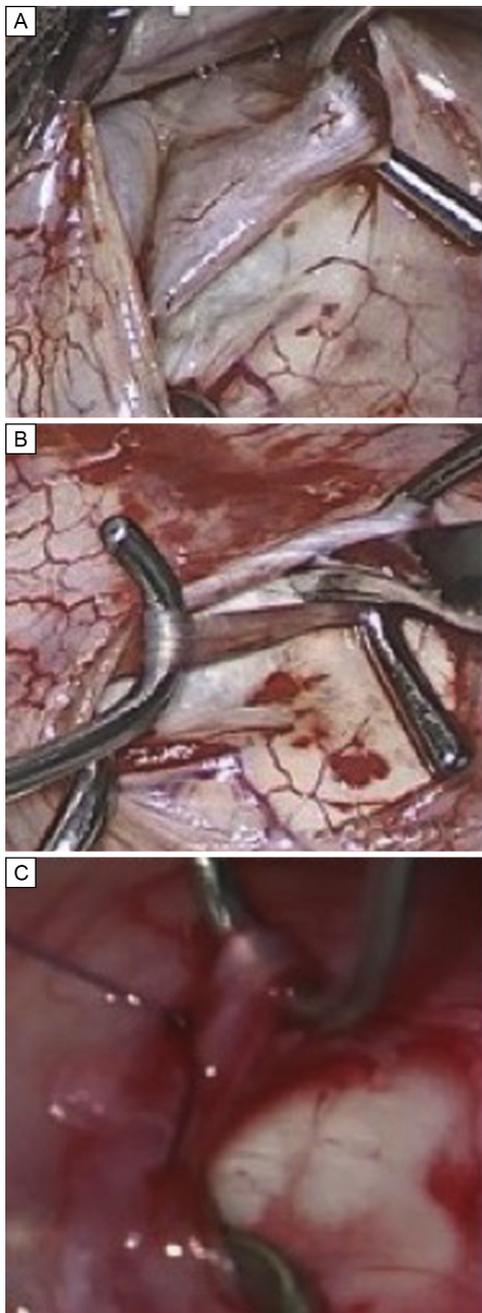
FIG 6. Superior oblique anterior fiber tuck. A, The superior oblique is isolated on a muscle hook. B, The superior oblique is divided into an anterior 1/4 and posterior 3/4. C, The anterior portion is tucked using a 6-0 polyglactin 910 suture.

The superior oblique muscle is the main intorter of the eye. The anterior fibers are responsible for torsion, whereas the posterior fibers have a depression and abducting function. Historically, selective surgery on the anterior fibers of the superior oblique tendon has been used to treat patients with torsional strabismus.[36]

Hoeckele and colleagues[42] recently reported a simpler procedure to treat excyclotropia consisting of an anterior superior oblique tuck. In 40 consecutive patients who underwent selective triangular tuck of the anterior portion of the superior oblique tendon, the mean excyclodeviation correction was 7°. Fifteen patients (38%) experienced a transient Brown syndrome which may have been caused by increased tension of the posterior fibers. To avoid this complication, a modified anterior superior oblique tuck has been introduced by Velez and Pineles.[43] This procedure is similar to the Harada-Ito in that the tendon is split into anterior and posterior portions but uses a tuck procedure similar to that described by Hoeckele and colleagues.[42]

Surgical Technique

A fornix-based incision is created, and the superior oblique is isolated on a muscle hook. The superior oblique tendon is then split similarly to a Harada-Ito procedure using sharp dissection to separate the anterior 1/4 and posterior 3/4 portions. The split is carried posteriorly between the nasal fibers of the superior rectus muscle and the insertion on the sclera as far posteriorly as possible. The anterior fibers of the superior oblique muscle are elevated using a small hook, and tucked, leaving the middle and posterior fibers untouched (Figure 6). A 6-0 polyglactin 910 suture is used to create a 5 mm tuck (5 mm total, with 2.5 mm on each side of the fold). The single-armed suture is passed through both sides of the folded tendon and tied. Forced duction testing must be performed to ensure that there is no restriction to elevation with the eye in adduction when moving the 6 o'clock limbus above the medial canthus.

In our experience, the amount of torsional correction from this procedure is approximately 7° immediately postoperatively, and none of our 5 patients have developed a limitation to elevation in adduction.[43] In our small cohort, the effect on torsion was stable in all but 1 patient, who had developed nonsymptomatic excyclotorsion of 5° by final follow-up, 75 days after the procedure (range of follow-up, 20-113 days).[43]

Conclusion

Adult strabismus is often complicated by incomitance, large or small size of deviation, and cyclodeviation. We have described several new techniques to add to the variety of treatment options in these cases. Innovation in our field is crucial to continue to address our patients' needs, and we look forward to further developments in surgical technique in the future.

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