Anatomy and Surgery of the Inferior Oblique Muscle: Recent Findings

David R. Stager, MD

Background: Surgery of the inferior oblique muscle (IO) has undergone significant changes in the past 160 years. Many investigators have contributed to our understanding of the action of this muscle and to the surgical options that have developed. This article reviews the history of IO surgery with particular emphasis on the anterior transposition procedure. ***Methods:*** Anatomic and physiologic studies on the neurofibrovascular bundle of the IO are presented. ***Results:*** The ligamentous structure of the neurofibrovascular bundle of the IO provides the ancillary origin for the posterior temporal fibers of the IO when its insertion is transposed anteriorly. ***Discussion:*** Recent anatomic findings have helped explain the effects of the anterior transposition procedure and allow further development of our surgical armamentarium for vertical strabismus problems. Further nasal transposition of that insertion should reduce or eliminate the incidence of the antielevation syndrome. If transposed far nasally, the IO could convert to an intorter, as well as to an antielevator and tonic depressor. (J AAPOS 2001;5:203-8)

The inferior oblique muscle (IO) has received a great deal of attention over the years, particularly for the past 20 years with the advent of the anterior transposition (AT) procedure (Figure 1). In 1841, Bonnet first described a myotomy of the IO from a nasal approach to treat asthenopia and myopia.[1] Duane, in 1906, was an advocate of this procedure to treat superior oblique palsy with overaction of the IO.[1] In the 1930s and 1940s, White and Brown[2] promoted the weakening of the IO at the insertional end of the muscle. At first, a disinsertion was suggested, but later several clinicians advocated a recession procedure.[3-6] In 1951, Fink[1] published his extensive anatomic studies on the oblique muscles and also advocated a recession of the IO as a weakening procedure. Dyer,[7] and later Costenbader and Kertesz,[8] believed that a myectomy was just as effective, and this belief has gained popularity at present in the United States. Parks[9] did a study comparing the effectiveness of IO weakening techniques and believed that the recession was superior. Gonzalez[10] was the first to suggest the denervation and extirpation procedure, which was further refined by Del Monte and Parks.[11]

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Submitted May 31, 2000.
Revisions accepted April 6, 2001.
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1091-8531/2001/$35.00 + 0 ***75/1/116273***
doi:10.1067/mpa.2001.116273

HISTORY

Anterior Transposition

Apt and Call[12] published a landmark study of 200 eye autopsies detailing the relationships of the IO to other structures, particularly the inferior rectus (IR) muscle. Figure 2 details these measurements by converting cord lengths to circumferential distances.

The AT procedure was developed in the 1980s and 1990s. Initially, Alan Scott,[13] Apt and Call,[12] and Elliott and Nankin[14] described an AT procedure that was designed to bring the insertion closer to the frontal plane containing the origin of the IO to enhance the weakening effect. Mims[15,16] found that this procedure eliminated the need for dissociated vertical deviation

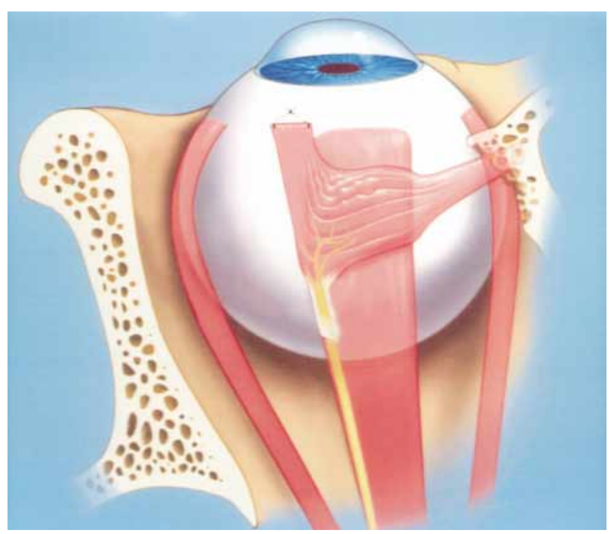

FIG 1. Traditional AT procedure.

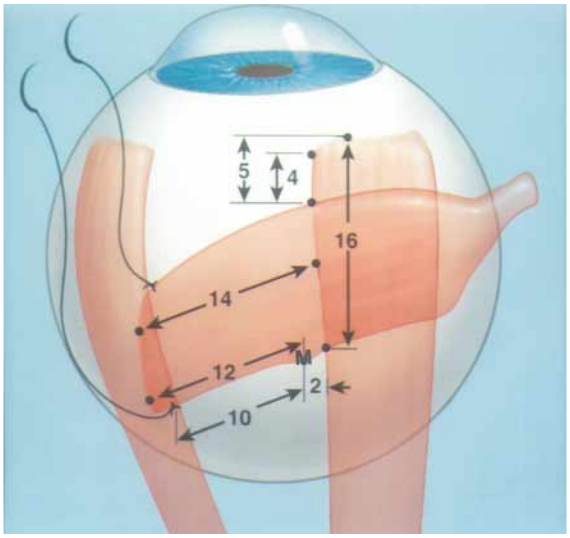

FIG 2. Relationships of IO to the IR. Myoneural junction of IO (ancillary origin).

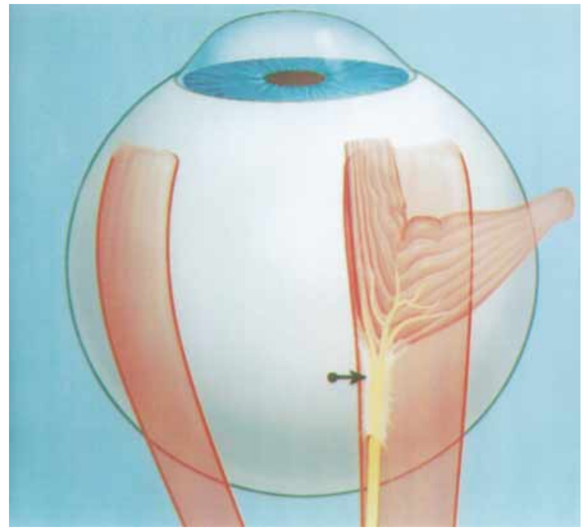

FIG 4. Modification of the traditional AT, attaching posterior fibers anterior to temporal extent of IR insertion.

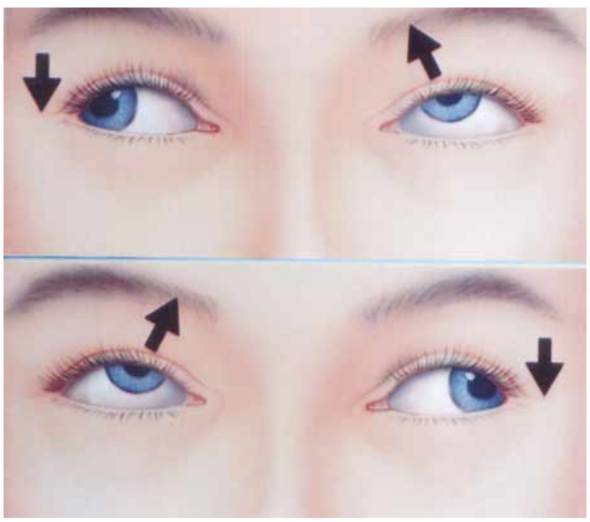

FIG 3. Recurrent elevation in adduction after bilateral IO AT.

FIG 5. Cadaver specimen of IR, IO, and its nerve. Reprinted with permission from the *Transactions of the American Ophthalmological Society.*[24] Copyright 1996, the American Ophthalmological Society.

surgery in the vast majority of cases. Thus, a technique of correcting both IO overaction and dissociated vertical deviation could be accomplished with one muscle procedure in each eye. Through the 1980s and 1990s, many articles confirming this effect were published. Bremer et al[17] discovered that, when performed unilaterally, this procedure could produce a significant hypotropia. Kratz et al[18] also reported that the effectiveness of this procedure on dissociated vertical deviation could be graded by moving the temporal suture further anterior or posterior. Years earlier, in 1977, Del Monte and Parks[11] noted the stiffness of the nerve during the course of performing a denervation and extirpation procedure. They noted that this structure seemed to hold the midportion of the muscle posterior following the disinsertion of the muscle. This was the first indication of a possible ancillary origin of the IO by way of its myoneural junction.

Antielevation Syndrome

In the past several years, articles by Kushner,[19] Stein and Ellis,[20] and Mims and Wood[21] have all addressed the issue of recurrent elevation in adduction after the AT procedure (Figure 3). The incidence after a bilateral AT procedure seems to be in the range of about 20% when the posterior fibers are placed 1 or 2 mm anterior and 3 to 5 mm temporal to the lateral border of the IR muscle insertion. The most recent article of Mims and Wood,[21] utilizing patients from Kushner's practice, determined that the incidence of this dropped when the temporal fibers are placed just anterior to the lateral border of the IR insertion. They termed the recurrent elevation in adduction *antielevation syndrome* and believed that it was primarily due to the taut posterior fibers that are placed temporally and have more tonic depression in abduction. In an unpublished study present-

FIG 6. Fibrous tissue bond extending from capsule of IR to capsule of IO (a portion of the capsulopalpebral head, or Lockwood's ligament).

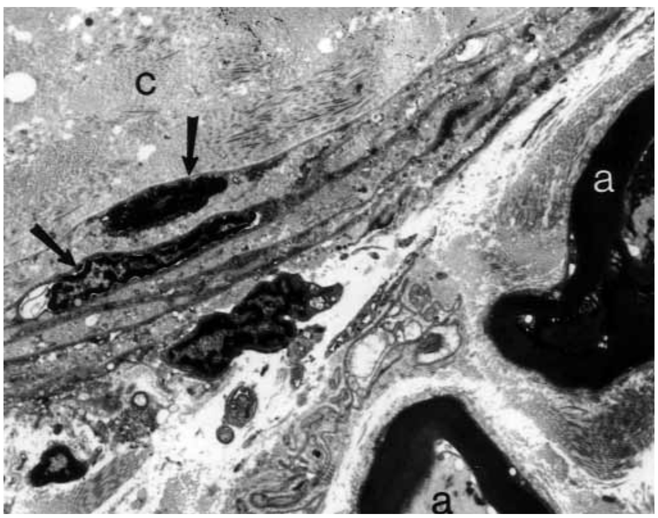

FIG 7. Electron microscopy of nerve of IO with thick layer of collagen fibers *(c)* parallel to the axons of the nerve *(a)*. Reprinted with permission from the *Transactions of the American Ophthalmological Society.*[24] Copyright 1996, the American Ophthalmological Society.

ed at the Jules Stein conference in April, 1998, I reported an 85% cure rate (+1 or less residual elevation in adduction) following nasal myectomy (a difficult procedure) in 20 patients with recurrent elevation in adduction. It has been my impression that the nasal 65% of the overacting IO could become attached by adhesions to the sclera that occur when the taut temporal fibers are anteriorly transposed. I have also observed that the insertion can migrate posteriorly, probably after the Vycril suture dissolves. Whether the recurrent elevation in adduction is due to the taut posterior and temporal transposed fibers or to the nasal 65% of the IO, I believe that this problem will disappear from our clinical practices as newer transposition techniques are used. Transposing the posterior and temporal fibers to the sclera adjacent to the temporal aspect of

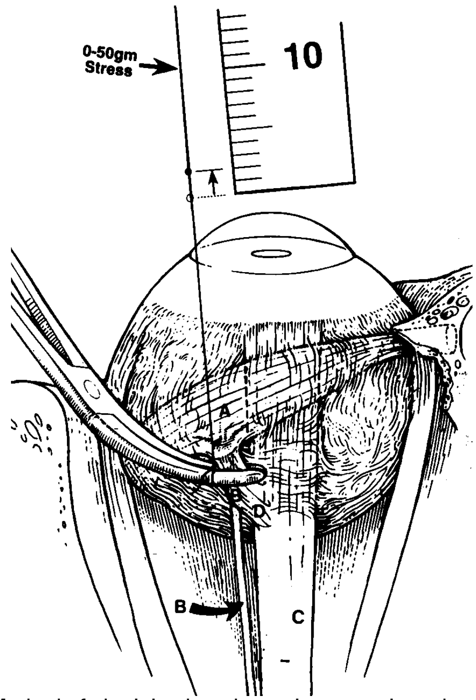

FIG 8. Method of obtaining length-tension curve in cadaver and surgical specimens with the hemostat at the myoneural junction. Reprinted with permission from the *Transactions of the American Ophthalmological Society.*[24] Copyright 1996, the American Ophthalmological Society.

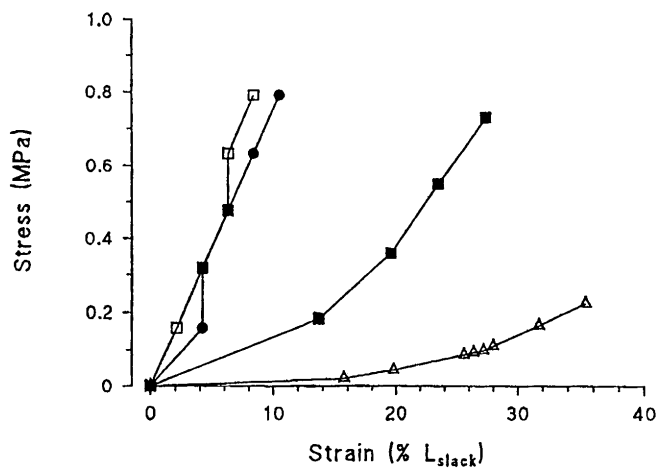

FIG 9. Average stress-strain curve of tested tissue. *Open squares:* In vivo surgical specimen. *Filled circles:* In vitro cadaver specimen neurofibrovascular bundle (NFVB). *Filled squares:* In situ cadaver specimen of the NFVB. *Open triangles:* In situ cadaver specimen superior oblique tendon. Reprinted with permission from the *Transactions of the American Ophthalmological Society.*[24] Copyright 1996, the American Ophthalmological Society.

the IR insertion, or even further nasally, just anteriorly to the nasal half of the IR, will quite likely eliminate this problem (Figure 4). As the insertion is displaced further nasally, so too the ancillary origin is displaced nasally by the vector forces of the overacting nasal portion of the IO.

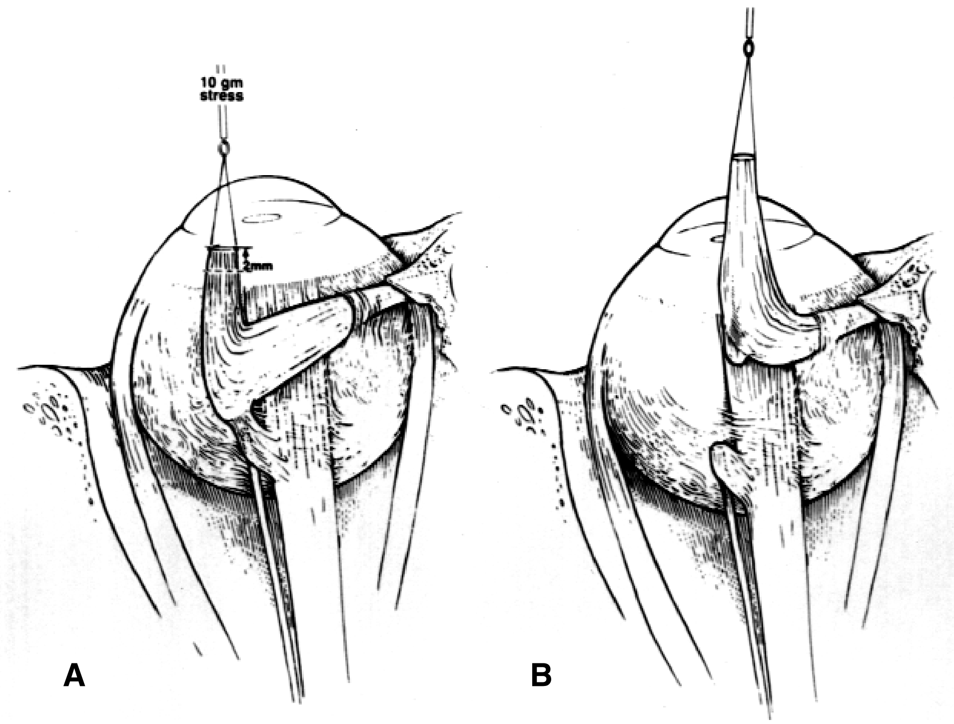

FIG 10. Identification of source of ancillary origin for IO muscle following AT procedure. **A,** Displacement after cutting intramuscular and fibrous attachments (2 mm). **B,** Displacement with same stress following denervation (14 mm). The ancillary origin stiffness arises from the nerve and the surrounding fibrous tissue that joins the capsules of the IO and IR. This fibrous tissue may be part of Lockwood's ligament. Reprinted with permission from the *Transactions of the American Ophthalmological Society.*[24] Copyright 1996, the American Ophthalmological Society.

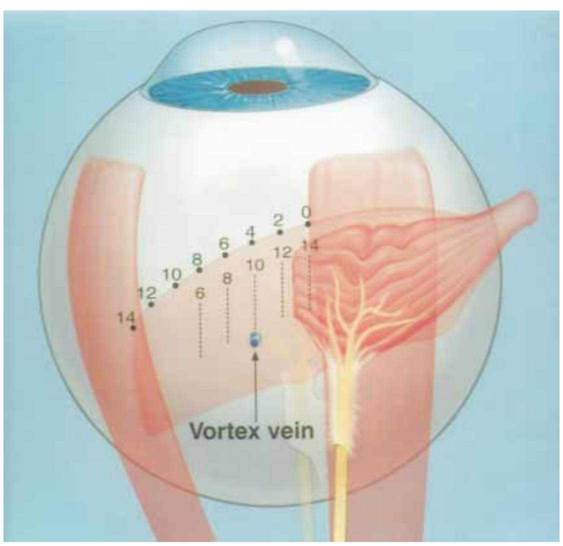

FIG 11. Pathway of pure recession procedure of the IO muscle. Lateral border of the IR is l4 mm from IO insertion. Anterior suture is attached 6 mm posterior to IR insertion and posterior suture 3 to 4 mm further posteriorly.

This combination then brings the taut, anteriorly transposed, posterior and temporal fibers to a position in which the IR will act as a cushion between the taut fibers and the sclera. Also, these taut fibers will be more in line with the y- and z-axes of Fick, reducing extortion and abduction. I look forward to the demise of the antielevation syndrome and the nasal myectomy with this adjustment in technique.

ANATOMIC STUDIES

So much has been written about how the AT acts as a tonic depressor and an antielevator; however, no one has really given a good explanation as to why this happens. Where is the origin? Is it the Lockwood's ligament or the neurofibrovascular bundle? We[22] did a radiographic study to demonstrate that a radio opaque clip on the myoneural junction did not move as the eye moved from primary gaze to upgaze. However, radiographic studies are prone to misinterpretation, and one letter to the editor[23] stated that it was not convincing evidence. We undertook studies[24] to determine that the nerve was linear and taut and that it indeed acted as the ancillary origin.

Eighteen fresh cadaver orbits were dissected, and it was shown that the nerve was linear (Figure 5) and shorter in length from the apex to the myoneural junction than the distance from the apex of the orbit to the origin of the IO. This would indicate that the route could not be very circuitous. Coronal sections of 2 whole intact orbits (courtesy of Dr Joseph Demer) were examined to determine the distance from the nerve to the IR muscle, and this was done from the myoneural junction of the IO to the apex of the globe. Again, we found an almost linear course with a very minor displacement due to postmortem orbital shrinkage.

Microscopic studies showed that the adjacent fibrous tissue identified in the anatomy laboratory (Figure 6) was composed of rather dense fibrous strands that attached to the capsule of the IR posteriorly and to the capsule of the IO anteriorly, just nasal to the nerve. Electron microscopy studies of the nerve showed a thick layer of collagen fibers all arranged parallel to the axis of the nerve (Figure 7). According to a letter he wrote in November 1995, J. Porter, PhD, believed that this was the anatomic basis for the stiffness of the nerve.

We performed length tension curves in the cadaver laboratory and at the time of surgery (Figure 8) and on isolated nerve segments in the physiology laboratory. This was compared with the stiffness of the superior oblique tendon taken from the same cadaver specimens. We found that the nerve and its adjacent fibrous tissue were 5 times as stiff as the superior oblique tendon and that the nerve itself was more than twice as stiff as the superior oblique tendon (Figure 9).

To determine whether this linear and taut structure was actually responsible for acting as an ancillary origin, we identified 6 patients who had recurrent IO overaction after an AT procedure. They were scheduled for a denervation and extirpation procedure. During the course of this operation, the muscle was disinserted and placed on stretch with a 10-g weight. The capsular and fibrous tissue surrounding the IR was then lysed, including Lockwood's ligament. The insertion moved forward just 2 mm. When the neurofibrovascular bundle was cut, the insertion moved forward 14 mm (Figure 10). Thus, we believed that this taut and linear structure was indeed responsible for acting as an ancillary origin.

DISCUSSION

The effect of the AT is multifold. It eliminates the normal action of the temporal 14 mm of the muscle and thus reduces significant IO overaction. It converts the posterior fibers of that muscle segment to a tonic depressor in the primary position and an antielevator, limiting upgaze to 30° to 35°. Because the new insertion may be situated temporal to the vertical axis of Fick, it also acts as an abductor, particularly when the muscle further contracts in upgaze. This produces a Y-pattern exotropia in upgaze. When performed unilaterally, it can markedly depress the eye, as stated previously. These effects may be dependent on how far temporally and anteriorly the muscle is attached to the globe. Complications include limited upgaze, possible recurrent contralateral elevation in adduction with Y-pattern exotropia in upgaze, and fullness of the lower lid.

Indications for this procedure include IO overaction in patients with congenital esotropia with dissociated vertical deviation or the potential for developing dissociated vertical deviation (90% in some studies). Also, patients with unilateral hypertropia in an amblyopic eye that previously has had horizontal rectus surgery may benefit from this procedure to correct the hypertropia without compromising the ciliary vessels of the superior or IR muscles. This may be more important in the elderly patient. Some people may prefer to do this procedure for pure IO overaction, and that may be quite suitable as long as they are aware of its limitations, particularly when done unilaterally.

True IO recession needs to be clarified in relation to the AT procedure. A pure recession moves the insertion of the IO nasally along the pathway of the muscle. For a l4-mm recession, according to Apt and Call,[12] we reattach the anterior fibers 6 mm posterior to the lateral border of the IR insertion and adjacent to the IR. The posterior fibers are attached 2 to 4 mm further posteriorly in a radial manner (Figure 12). Moving the insertion further temporal and posterior will reduce the recession.

Predictions

Future advancements will certainly be occurring in this area, including the work with the muscle pulley system and how that affects this muscle. Permanent sutures may need to be used to prevent posterior migration of these taut fibers. Some have suggested resecting a portion of the muscle at its insertional end when performing the AT to produce an asymmetric result. Studies will need to be undertaken on the effectiveness of that technique. There may be special muscle problems such as severe elevation in adduction, particularly with craniofacial dysostosis and missing superior oblique muscles, in which transposing the posterior fibers to an area between the IR and the medial rectus muscle may be more effective at converting the posterior muscle fibers from an elevator and extorter to a depressor and intorter. I am looking forward to much more exciting and innovative work to be done in this area.

I would like to thank the following individuals for their invaluable assistance with this study: A. Anon, MD; John Porter, PhD; Eileen Birch, PhD; David R. Stager, Jr, MD; Joseph L. Demer, MD; D. Brian Stidham, MD; Mary Everett, CO; David R. Weakley, MD; and Marshall M. Parks, MD.

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An Eye on the Arts – The Arts on the Eye

Her work with surgical lasers had won her a Lasker Public Service Award—the highest such award in American medicine—but it hadn't been fundamental enough for a trip to Stockholm. That was fine with her. Ophthalmology wasn't that sort of field, but fixing people's sight was pretty damned rewarding. Maybe the one good thing about Jack's elevation and her attendant status as First Lady was that she'd have a real shot at the Directorship of the Wilmer Institute if and when Bernie Katz ever decided to hang it up. She'd still be able to practice medicine—that was something she never wanted to give up—and also be able to oversee research in her field, decide who got the grants, where the really important exploratory work was, and that, she thought, was something she might be good at. So, maybe this President stuff wasn't a total loss.

—Tom Clancy (from *The Bear and the Dragon* p 352)