Two Hypothetical Nystagmus Procedures: Augmented Tenotomy and Reattachment and Augmented Tendon Suture (*Sans* Tenotomy)

Louis F. Dell'Osso, PhD; Robert L. Tomsak, MD, PhD; Matthew J. Thurtell, MBBS

ABSTRACT

Purpose: To review the hypothetical mechanism and therapeutic benefits of the four-muscle tenotomy and reattachment (T&R) procedure using knowledge accrued over the 10 years since its proposal; to describe an augmented tendon suture (ATS) technique to improve the procedure based on one of the originally suggested alternative methods (mechanical); and to hypothesize a new ATS procedure to achieve the same therapeutic benefits without extraocular muscle tenotomy or reattachment to the globe.

Methods: Standard surgical methods were used.

Results: The T&R procedure damps and improves infantile nystagmus syndrome (INS) waveforms, improves eXtended Nystagmus Acuity Function (NAFX) values, broadens the NAFX peak versus gaze angle, and damps slow eye movements but not saccades. The T&R procedure also damps acquired pendular and downbeat nystagmus, decreasing the patients' oscillopsia, and lowers the target acquisition time in INS.

Conclusion: The T&R procedure directly affects only the enthesis of the tendon; there is idiosyncratic variation in the distribution of afferent fibers in the tendons. The ATS technique consists of placing several additional sutures in the tendon proximal to the tenotomy. Based on the hypothetical proprioceptive mechanism for the beneficial effects of the T&R procedure, the authors hypothesize that the ATS technique will maximize the therapeutic benefits and that an ATS procedure, using only tendon sutures without tenotomy, will duplicate the therapeutic effects of T&R. Eliminating the tenotomy component results in a simpler procedure more suitable for single-session, multi-muscle surgery that may be required for improving the waveforms of multiplanar nystagmus and less prone to cause complications.

[J Pediatr Ophthalmol Strabismus 2009;46:337-344.]

INTRODUCTION

Although patients with infantile nystagmus syndrome (INS) do not suffer from oscillopsia, they do experience lowered visual acuity. This is the reason for therapeutic intervention in these patients. In 1979, the results of the first ocular motor study of the effects of the Kestenbaum procedure on INS suggested a new type of nystagmus sur-

From the Daroff-Dell'Osso Ocular Motility Laboratory (LFD, RLT, MJT), Louis Stokes Cleveland Department of Veterans Affairs Medical Center and CASE Medical School, Cleveland, Ohio; the Departments of Neurology (LFD, RLT, MJT) and Biomedical Engineering (LFD), Case Western Reserve University and University Hospitals Case Medical Center, Cleveland, Ohio; and the Department of Neurology (MJT), Institute of Clinical Neurosciences, Royal Prince Alfred Hospital, and the University of Sydney, Sydney, Australia.

Originally submitted November 12, 2008. Accepted for publication December 10, 2008. Posted online July 22, 2009.

Presented in part at the 2009 Asia–Association for Research in Vision and Ophthalmology meeting, January 15-18, 2009, Hyderabad, India, and the North American Neuro-Ophthalmology Society annual meeting, February 21-26, 2009, Lake Tahoe, California.

Supported in part by the Office of Research and Development, Medical Research Service, Department of Veterans Affairs.

The authors have no financial or proprietary interest in the materials presented herein.

Address correspondence to Louis F. Dell'Osso, PhD, Daroff-Dell'Osso Ocular Motility Laboratory, Louis Stokes Cleveland Veterans Affairs Medical Center, 10701 East Boulevard, Cleveland, OH 44106.

doi: 10.3928/01913913-20091104-05

gery.[1,2] The authors noted that, in addition to the expected shift of the INS null region to primary position, the Kestenbaum procedure broadened the null region and improved nystagmus waveforms. It was proposed that these unexpected and therapeutically beneficial changes in the nystagmus resulted from the obligate tenotomy and resuture portions of the procedure.

A decade ago, this surgery, "the tenotomy procedure," was formally hypothesized to produce beneficial changes in INS.[3] The surgery actually consists of the tenotomy and reattachment (resuture) (T&R) of the tendons at their original insertions. Unlike strabismus procedures, this pure nystagmus procedure required no repositioning of the muscles on the globe. The ophthalmological community's initial response to this proposed nystagmus surgery was both unanimous and less than enthusiastic (eg, "it would not/could not work").

In this article, we review nystagmus surgery procedures relevant to the current T&R procedure and suggest possible modifications to the latter based on its hypothetical mechanism of action. We further hypothesize a new tendon suture procedure that could eliminate the need for tenotomy entirely.

BRIEF HISTORY OF RELEVANT INS SURGERY

"Nystagmus" surgery has classically been performed to correct anomalous head positions, whereas "strabismus" surgery has been performed to improve ocular alignment. Although both types of extraocular muscle (EOM) surgery employ the same surgical techniques, they are different in their aims and their outcome measures and, therefore, they should not be lumped under the rubric of "strabismus surgery." Whereas in strabismus surgery one or both eyes are moved disconjugately to achieve static alignment in patients whose eyes are misaligned, in nystagmus surgery, both eyes may be moved conjugately (Kestenbaum procedure), disconjugately (bimedial rectus recessions), or not at all (T&R procedure) to achieve dynamic improvement in the nystagmus waveform, independent of static eye alignment.

In 1979, improvement of visual performance was unexpectedly identified as a result of nystagmus surgery.[1] Two main types of nystagmus surgery have been advocated: conjugate shifting of the eyes to reposition an eccentric nystagmus gaze angle "null" to primary position or creating a mild divergence of the aligned eyes of orthophoric, binocular patients to take advantage of a convergence angle null. For the first type, Anderson proposed paired rectus muscle recessions,[4] Kestenbaum proposed paired recessions and resections,[5,6] and Goto proposed paired resections.[7] For the second type, Cüppers proposed bimedial rectus muscle recessions—artificial divergence surgery.[8] Vertical gaze angle nulls may be corrected using the same procedures on the vertical rectus muscles.[9-11] The above nystagmus surgeries can easily be combined with any required strabismus surgery in those patients with both INS and strabismus. Recently, a more extensive review of these and other procedures was published.[12]

Common to the above procedures was the repositioning or alteration of one (or more) EOM by either recessing or resecting it with the stated purpose of either "strengthening" or "weakening" its action. This stress on the purely mechanical approach to nystagmus surgery has recently been replaced by an approach in which it is recognized that nystagmus is primarily a disorder of the neurological control system that directs and stabilizes the eyes. It became clear that, in addition to any static gaze angle or vergence angle characteristics of the nystagmus that could, and should, be exploited mechanically by repositioning the muscles, or in cases where there were no such static characteristics, there remained the need to minimize the ocular motor oscillation itself and improve target foveation over a broad range of gaze angles. Reducing the "small-signal" gain of the EOM accomplishes this.[13] The shift in emphasis from repositioning or otherwise mechanically changing the actions of EOMs to altering their role in the manifestation of nystagmus represents a basic paradigm shift in nystagmus surgery.

Now, a decade after the tenotomy procedure was initially proposed, it is time to move forward and suggest ways to improve the T&R procedure, based on: (1) its hypothetical mechanism, as discussed in earlier publications,[13,14] and (2) the knowledge we have accumulated by studying the effects of the T&R procedure in patients with either INS or different types of acquired nystagmus.[15-20] In this article, we suggest several small tendon-suture modifications to the current procedure, as well as a possible replacement of the tenotomy procedure with a simple augmented tendon-suture procedure that we propose will have equivalent therapeutic benefits without the need for, or possible complications (albeit minimal) of, T&R.

FOUR-MUSCLE TENOTOMY AND REATTACHMENT PROCEDURE

Surgical Technique (used by RLT)

The T&R surgical procedure consists of preparing the patient in the usual way for eye muscle surgery. The muscle to be operated on is accessed by a fornix-based peritomy starting at the limbus. The muscle is isolated on a Jameson hook and cleaned with sharp dissection. Thereafter, a double-armed 6-0 polyglactin 910 suture is woven through the muscle and locked on each side. The muscle is cut from the globe and then reattached at the insertion. The conjunctiva is closed by coaptation if possible, or with 8-0 polyglactin 910 sutures if needed. Figure 1A shows the current T&R procedure.

Ocular Motor Results

The ocular motor effects of the T&R procedure on INS include damping the nystagmus and improving target foveation, as measured by the eXpanded Nystagmus Acuity Function (NAFX).[15,16,18,19,21] The NAFX is a function that yields, as a number, an indication of the quality of target foveation. These effects are restricted to slow eye movements (ie, saccades are unaffected).[13]

Therapeutic Results

Therapeutically, broadening the NAFX versus gaze angle curve effectively increases the range of gaze angles within which visual acuity remains at or near its peak.[15,16,18] Improvement of the peak NAFX value allows for a higher visual acuity following T&R.[15,16,18] The therapeutic improvements documented in INS have also been demonstrated in patients with acquired nystagmus, with the added benefit of reduced oscillopsia.[17,19] In addition, the T&R procedure resulted in faster target acquisition times in patients with INS.[20,22] Combining the T&R results from many patients has allowed us to develop a NAFX-based method of estimating potential therapeutic results prior to surgery.[18,21,23]

DISCUSSION

It should be stressed that, like the Kestenbaum procedure, the traditional T&R procedure is a four-muscle technique involving the four muscles (two per eye) in the plane (or major plane) of the nystagmus. All ocular motor data demonstrating the T&R procedure's therapeutic benefits thus far have employed this technique.[14-20] Currently, there have been no ocular motor studies to evaluate whether two-muscle procedures (eg, the one muscle per eye Anderson or Goto) will have any (or equivalent) beneficial effects on broadening the INS high-NAFX peak (usually corresponding to the INS null), raising that peak value, or decreasing the target acquisition time. Thus, two-muscle, gaze-shifting procedures cannot be recommended at this time and should not be substituted for four-muscle INS surgeries; the sole exception is the bimedial rectus muscle recession (artificial divergence) procedure—creating artificial divergence—for binocular patients whose INS damps with convergence.[24,25]

However, if bimedial rectus muscle recessions (a strabismus procedure) are done to correct an esotropia in a patient with INS, both lateral rectus muscles should also receive the T&R nystagmus procedure to damp the INS. Also, simple one- or two-muscle strabismus procedures (eg, recessions) are insufficient to achieve the desired waveform improvements in patients with INS who have strabismus; they must be augmented (usually by T&R) to include all four EOMs in the plane of the INS. Preliminary, unpublished data from our laboratory suggest that strabismus surgery plus the T&R procedure may also be beneficial for patients with fusion maldevelopment nystagmus syndrome. Thus, for this type of nystagmus, just as for several different types of acquired nystagmus, the T&R procedure would work at the EOMs to damp the nystagmus, independent of its site or functional source.

Original Suggestions. The four-muscle T&R procedure was based on the analysis of eye movement data from patients with INS undergoing the Kestenbaum procedure.[1,3,14] Therefore, to test the hypothesis that the tenotomy and resuture portion produced the desired secondary therapeutic effects, it was necessary that we duplicate the Kestenbaum procedure in all ways without performing the actual recessions and resections. Only in that way could it be proven that the measured secondary effects of the Kestenbaum procedure were not due to the muscle repositioning. However, even from that earliest stage of our studies, it was hypothesized that other, less invasive techniques could prove to be equally effective so that the actual muscle tenotomy and resuture to the globe could be avoided.[14,26] Those prior suggestions ranged from simply mechanically deforming the proprioceptive endings to thermal or chemical alteration, all without tenotomy.

Hypothetical Mechanism. The mechanism by which the T&R procedure damps and improves INS waveforms has been hypothesized to be due to an alteration in a proprioceptive tension control loop in the EOMs.[14,15] The proprioceptively changed gain of the ocular motor "plant" was limited to the slow signals in the INS; saccades were unaffected.[13] This required a dual-path ocular motor plant, one for saccades and the other for slow movements, and an active role for proprioception in ocular motor control. Recently, new anatomical evidence in support of the proprioceptive hypothesis has been published.[27-30] Separate populations of ocular motor neurons have been discovered, one for all eye movements and the other restricted to slow eye movements, which provide a mechanism for tenotomy only affecting the latter. In addition, proprioceptive eye movement signals have recently been recorded in the cortex in addition to their known projections to the brain stem.[30]

In the original T&R procedure, each tendon is resutured to the globe at its original insertion. It is not currently known how many fibers from the proprioceptive endings at the musculotendon interface travel more distally or how far they travel toward the enthesis. Furthermore, we do not know the intersubject distribution of these structures (personal communication, Jean Buettner-Ennever, MD, July 2008). However, we do not believe that tenotomy at the enthesis directly damages the proprioceptive endings, but it is reasonable to presume that the closer to the musculotendon junction that sutures are placed, the more such fibers would be affected.

Before proceeding, considerations of putative mechanistic details that may play a role in the hypothesized proprioceptive mechanism are necessary. What exactly is happening at the site of the tenotomy and reattachment and are the proprioceptive muscle tension signals affected? Tenotomy and suture are known to cause mechanical deformation, local ischemia, inflammation, some cell death, and scarring at the site. Although each of these processes may play some role in generating the lowered muscle gain to small signals that results in damped nystagmus without affecting saccades,[13] the extent of their individual contribution is not known.

What could cause the proprioceptors to increase their firing and thereby signal the brain to reduce resting muscle tension? One possibility is that no proprioceptive fibers travel all the way to the point of tendon attachment to the sclera. If so, the T&R procedure would not directly affect any proprioceptive fibers. Any relaxation arising due to modification of the proprioceptive tension control loop would have to be in response to a real increase in muscle tension, perhaps caused by scarring or a small virtual resection caused by the tenotomy and suturing of the tendon (ie, the muscle is stretched slightly). The resulting relaxation of steady-state innervation to the muscle would put it on a lower portion of the length-tension curve (or move the curve) with the result that, due to the lower slope of the curve at that operating point, the small signal gain would be lower.[13]

Another possibility is that the proprioceptive fibers are directly affected by the T&R procedure, either because they travel all the way to the point of tendon insertion into the globe or they are affected by manipulation of the tendon during surgery. Then it is possible that even if no additional muscle tension resulted, the fibers could fire at a higher rate due to the irritative stimulus provided by the T&R procedure. Again, the small-signal gain would be lowered. What if those proprioceptive fibers were damaged by the procedure? Then the proprioceptive signal to the brain from those fibers could be interrupted, reducing the overall tension signal to the brain, and would presumably result in increased muscle tension due to the negative feedback, tension control loop. Such a mechanism would be counterproductive and, given the observed small-signal gain reduction, is an unlikely possibility.

AUGMENTED FOUR-MUSCLE TENOTOMY AND REATTACHMENT PROCEDURE

Suggested Interim Steps

The purpose of the T&R procedure was to broaden the range of gaze angles where the patient's highest acuity would prevail and to raise the value of that highest acuity.[1,18] Because of the intersubject variability of INS waveforms and sharpness of the NAFX versus gaze angle peaks, the therapeutic improvements were also expected to vary along predictable curves.[26] Prior suggestions to improve the T&R procedure included mechanical, cryogenic, and chemical methods.[14,26] Although study of cryogenic and chemical techniques will have to await animal experiments, mechanical techniques lend themselves to immediate application in patient surgeries (eg, merely adding sutures along the EOM tendons may maximize the effects on the proprio-

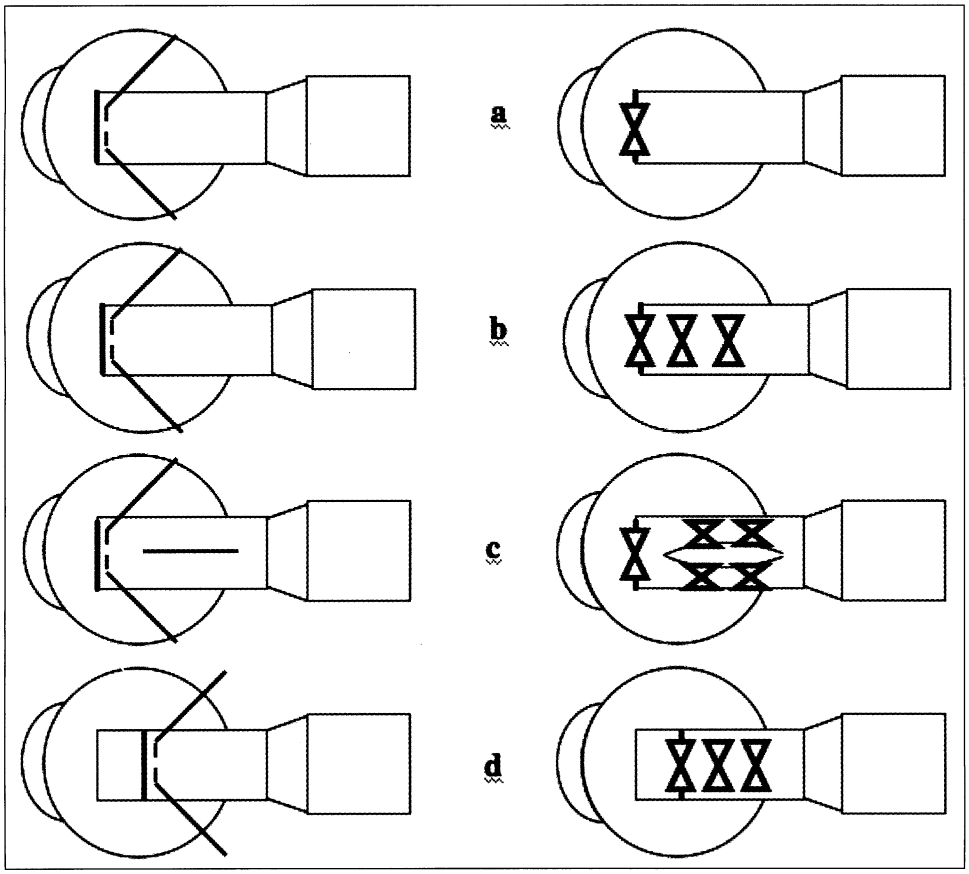

Figure 1. Diagrams of (A) the original tenotomy procedure and augmented tenotomy procedures consisting of tenotomy at the globe plus (B) augmented tendon suture or (C) split-tendon, augmented tendon suture. (D) Diagram of the proposed distal tendon tenotomy, augmented tendon suture procedure. In this and Figure 2, bold lines indicate sites of: tenotomy or tendon splitting; placement of the crossed-swords, double-armed suture prior to tenotomy (in left panels) and reattachment and extra sutures (in right panels). The additional sutures in (B) and (C) (two and four, respectively) and all sutures in (D) are placed in the tendon only, no attachment to the globe.

ceptive receptors). These stand-alone sutures should also produce inflammation, local ischemia, and scarring, potentially adding to the effects of the original procedure by increasing the amount of change to the proprioceptive, tendon–tension sensors.

Surgical Techniques

The following modifications to the original T&R procedure are simple, mechanical changes that could be easily incorporated into current practice. They are the simple augmented tendon suture (ATS) method; split-tendon ATS method; and distal tendon tenotomy, ATS method.

Simple ATS Method. After placing a crossed-swords, double-armed suture and performing the tenotomy and reattachment at the original insertion, one or two additional sutures are placed closer to the myotendonous junction than the one that reattaches the tendon to the globe (see Fig. 1B showing two additional sutures). These additional sutures are placed in the tendon only; they do not attach the tendon to the globe.

Split-Tendon ATS Method. After placing a crossed-swords, double-armed suture and performing the tenotomy and reattachment at the original insertion, the tendon is split longitudinally and one or two additional sutures are placed in each portion (see Fig. 1C showing four additional sutures). These additional sutures are placed in the tendon only; they do not attach the tendon to the globe.

Distal Tendon Tenotomy, ATS Method. After placing a crossed-swords, double-armed suture, the tenotomy is performed at the distal portion of the tendon instead of at its insertion into the globe, the two parts of the tendon are resutured together, and one or two additional sutures are placed closer to the myotendonous junction (see Fig. 1D showing two additional sutures). Both the suture reattaching the tendon and the additional sutures are placed in the tendon only; they do not attach the tendon to the globe.

Each of these modification techniques preserves the basic elements of the four-muscle T&R procedure: tenotomy and reattachment of the tendon without changing the original site of muscle insertion. However, the distal tendon technique has the additional advantage of reducing the admittedly small possibility of accidental perforation of

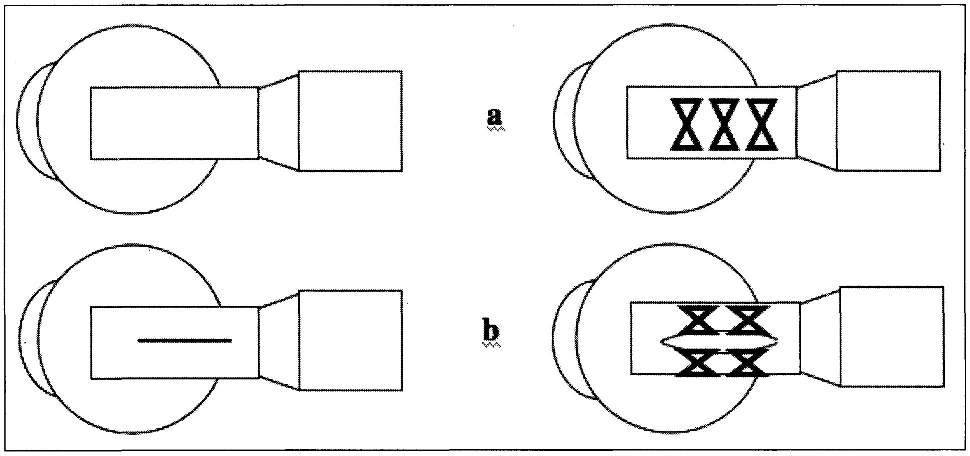

Figure 2. Diagrams of the proposed augmented tendon suture procedure without tenotomy: (A) augmented tendon suture or (B) split-tendon, augmented tendon suture. All sutures in (A) and (B) are placed in the tendon only, no attachment to the globe.

the globe during the tenotomy or while suturing the tendon to the globe. One caveat is that cutting across the distal tendon may injure those few of the proprioceptive fibers that travel that far into the tendon and reduce the desired effect slightly.

FOUR-MUSCLE AUGMENTED TENDON SUTURE PROCEDURE

The Next Paradigm Shift

As indicated by the earlier suggestions for either duplicating or improving the tenotomy procedure, it was recognized that the tenotomy portion itself was most probably not necessary and could be eliminated,[26] especially because it is the portion that is most likely to cause significant complications (during either the tenotomy or resuturing to the globe). As discussed above, each suture should produce irritation, local ischemia, and scarring, thereby causing the same results as the original T&R procedure with neither the need for nor the potential problems of T&R. These considerations led us to propose a four-muscle, augmented tendon suture (ATS) procedure.

Surgical Techniques

When results measured from the above modification techniques become available, the two techniques described below may be considered; essentially, they consist of simply eliminating the tenotomy and reattachment portion of the above modified techniques. If one of the techniques is demonstrably better, it should be used as the method of choice for the proposed augmented suture procedure; if not, either can be used.

Simple ATS Method. As a first step (ie, with no tenotomy), two or three sutures are placed closer to the myotendonous junction than the attachment of the tendon to the globe (see Fig. 2A showing three sutures). These sutures are placed in the tendon only; they do not attach the tendon to the globe.

Split-Tendon ATS Method. As a first step (ie, with no tenotomy), the tendon is split longitudinally and one or two sutures are placed in each portion (see Fig. 2B showing four sutures). These sutures are placed in the tendon only; they do not attach the tendon to the globe.

The medial rectus tendon contains two ciliary blood vessels and the lateral rectus tendon contains one; they supply the anterior segment of the eye. As an added precaution, especially when both the horizontal and vertical rectus muscles require ATS (see below), the sutures can be placed to avoid these easily visualized vessels.

Additional Benefit for Complex Cases

The four-muscle T&R procedure for uniplanar nystagmus carries with it no danger of anterior segment ischemia because, like the Kestenbaum procedure, only two of the four rectus muscles of each eye are detached. However, biplanar or triplanar nystagmus (eg, the nystagmus exhibited by some patients with INS and all patients with achiasma) may require T&R of both sets of rectus muscles of each eye (eg, biplanar INS) or even all six EOMs of each eye (eg, biplanar INS plus see-saw nystagmus). Currently, this requires doing two procedures separated by 4 to 6 months to allow revascularization and prevent anterior segment ischemia. Usually, the four rectus muscles in the major plane of the nystagmus undergo the standard T&R procedure and the remaining four rectus muscles (plus the four oblique muscles in the case of see-saw nystagmus) are operated on in the second procedure (personal communication, Richard W. Hertle, MD, 1998).[14] The ATS procedure alleviates concerns about anterior segment ischemia, allowing all necessary muscle tendons for each patient to be sutured at the same time, and also eliminating the need (and associated costs) for, and problems with, a second procedure.

ROADMAP TO ELIMINATING TENOTOMY

The split-tendon ATS modifications were included for completeness; our initial exploration of the effects of the ATS techniques will be confined to the simple ATS procedures. It is possible that the split-tendon technique might have unintended mechanical consequences, such as causing an infranuclear mechanical form of strabismus, although we think that is unlikely in binocular patients, where artificial divergence procedures are easily compensated for. This more complex technique could confound our data and should be studied at a later date.

The simple ATS modifications only involve placing absorbable sutures into the tendon so they can easily be incorporated into the T&R procedure as a matter of choice by an individual surgeon. Similarly, the distal tendon tenotomy, ATS modification can also be chosen because it is safer and fulfils all of the mechanistically important criteria of the original T&R procedure. Based on the putative mechanisms discussed above, we expect each of these modifications to provide at least the same benefits as the original T&R procedure.

As a first step toward the elimination of the tenotomy portion of T&R, the ATS procedure can easily be incorporated into surgeries where only one or two EOMs would traditionally receive recessions (eg, Anderson or strabismus procedures) by adding the augmented sutures to the antagonist muscles. If no change in the NAFX peak results, our hypothesis would be disproved and attention should be shifted to the sclerotendinous junction where innervated myotendinous cylinders have been found.[31,32] However, if the NAFX peak is broadened as we expect, it would establish the efficacy of the procedure and at the same time not negatively affect the muscle repositioning outcome of the recessions. The ATS procedure (sans tenotomy) could then reasonably be substituted for the augmented T&R procedure. We hypothesize that the ATS procedure will provide the same therapeutic benefits as the T&R (ie, patients will see "more," "better," and "faster").[20]

REFERENCES

1. Dell'Osso LF, Flynn JT. Congenital nystagmus surgery: a quantitative evaluation of the effects. *Arch Ophthalmol.* 1979;97:462-469.
2. CEMAS Working Group. *A National Eye Institute Sponsored Workshop and Publication on the Classification of Eye Movement Abnormalities and Strabismus (CEMAS).* Bethesda, MD: National Institutes of Health, National Eye Institute; 2001.
3. Dell'Osso LF. Extraocular muscle tenotomy, dissection, and suture: a hypothetical therapy for congenital nystagmus. *J Pediatr Ophthalmol Strabismus.* 1998;35:232-233.
4. Anderson JR. Causes and treatment of congenital eccentric nystagmus. *Br J Ophthalmol.* 1953;37:267-281.
5. Kestenbaum A. Nouvelle operation de nystagmus. *Bull Soc Ophtalmol Fr.* 1953;6:599-602.
6. Kestenbaum A. A nystagmus operation. *Acta XVII Council Ophthalmol (Canada, US).* 1954;Ii:1071-1078.
7. Goto N. A study of optic nystagmus by the electro-oculogram. *Acta Soc Ophthalmol Jpn.* 1954;58:851-865.
8. Cüppers C. Probleme der operativen Therapie des okulären Nystagmus. *Klin Monatsbl Augenheilkd.* 1971;159:145-157.
9. Pierse D. Operation on the vertical muscles in cases of nystagmus. *Br J Ophthalmol.* 1959;43:230-233.
10. Yang MB, Pou-Vendrell CR, Archer SM, Martonyi EJ, Del Monte MA. Vertical rectus muscle surgery for nystagmus patients with vertical abnormal head posture. *J AAPOS.* 2004;8:299-309.
11. Greenberg MF, Pollard ZF. Superior oblique tendon expanders with inferior rectus recessions for chin-up null point nystagmus. *J AAPOS.* 2007;11:201-203.
12. Tomsak RL. Eye muscle surgery for acquired forms of nystagmus. In: Leigh RJ, Devereaux MW, eds. *Advances in Understanding Mechanisms and Treatment of Congenital Forms of Nystagmus.* New York: Oxford University Press; 2008:112-116.
13. Wang Z, Dell'Osso LF, Zhang Z, Leigh RJ, Jacobs JB. Tenotomy does not affect saccadic velocities: support for the "small-signal" gain hypothesis. *Vision Res.* 2006;46:2259-2267.
14. Dell'Osso LF, Hertle RW, Williams RW, Jacobs JB. A new surgery for congenital nystagmus: effects of tenotomy on an achiasmatic canine and the role of extraocular proprioception. *J AAPOS.* 1999;3:166-182.
15. Hertle RW, Dell'Osso LF, FitzGibbon EJ, et al. Horizontal rectus tenotomy in patients with congenital nystagmus: results in 10 adults. *Ophthalmology.* 2003;110:2097-2105.
16. Hertle RW, Dell'Osso LF, FitzGibbon EJ, Yang D, Mellow SD. Horizontal rectus muscle tenotomy in patients with infantile nystagmus syndrome: a pilot study. *J AAPOS.* 2004;8:539-548.
17. Tomsak RL, Dell'Osso LF, Rucker JC, et al. Treatment of acquired pendular nystagmus from multiple sclerosis with eye muscle surgery followed by oral memantine. *Digital Journal of Ophthalmology.* 2005;11:1-11.
18. Wang Z, Dell'Osso LF, Jacobs JB, Burnstine RA, Tomsak RL. Effects of tenotomy on patients with infantile nystagmus syndrome: foveation improvement over a broadened visual field. *J AAPOS.* 2006;10:552-560.
19. Wang ZI, Dell'Osso LF, Tomsak RL, Jacobs JB. Combining recessions (nystagmus and strabismus) with tenotomy improved visual function and decreased oscillopsia and diplopia in acquired downbeat nystagmus and in horizontal infantile nystagmus syndrome. *J AAPOS.* 2007;11:135-141.
20. Wang ZI, Dell'Osso LF. Tenotomy procedure alleviates the "slow to see" phenomenon in infantile nystagmus syndrome: model prediction and patient data. *Vision Res.* 2008;48:1409-1419.
21. Dell'Osso LF, Jacobs JB. An expanded nystagmus acuity function: intra- and intersubject prediction of best-corrected visual acuity. *Doc Ophthalmol.* 2002;104:249-276.
22. Wang ZI, Dell'Osso LF. Being "slow to see" is a dynamic visual function consequence of infantile nystagmus syndrome: model predictions and patient data identify stimulus timing as its cause. *Vision Res.* 2007;47:1550-1560.
23. Dell'Osso LF. New treatments for infantile and other forms of nystagmus. In: Leigh RJ, Devereaux MW, eds. *Advances in Understanding Mechanisms and Treatment of Congenital Forms of Nystag-*

mus. New York: Oxford University Press; 2008:87-98.
24. Serra A, Dell'Osso LF, Jacobs JB, Burnstine RA. Combined gaze-angle and vergence variation in infantile nystagmus: two therapies that improve the high-visual acuity field and methods to measure it. *Invest Ophthalmol Vis Sci.* 2006;47:2451-2460.
25. Dell'Osso LF, Wang ZI. Extraocular proprioception and new treatments for infantile nystagmus syndrome. In: Kennard C, Leigh RJ, eds. *Using Eye Movements as an Experimental Probe of Brain Function, A Symposium in Honour of Jean Büttner-Ennever* (vol. 171). Philadelphia: Elsevier; 2008:67-75.
26. Wang ZI, Dell'Osso LF. A review of the tenotomy nystagmus surgery: origin, mechanism, and general efficacy. *Neuroophthalmol.* 2007;31:157-165.
27. Büttner-Ennever JA, Horn AKE, Scherberger H, D'Ascanio P. Motoneurons of twitch and non-twitch extraocular fibres in the abducens, trochlear and oculomotor nuclei of monkeys. *J Comp Neurol.* 2001;438:318-335.
28. Büttner-Ennever JA, Horn AKE, Graf W, Ugolini G. Modern concepts of brainstem anatomy: from extraocular motoneurons to proprioceptive pathways. *Ann N Y Acad Sci.* 2002;956:75-84.
29. Ugolini G, Klam F, Doldan Dans M, et al. Horizontal eye movement networks in primates as revealed by retrograde transneuronal transfer of rabies virus: differences in monosynaptic input to "slow" and "fast" abducens motoneurons. *J Comp Neurol.* 2006;498:762-785.
30. Wang X, Zhang M, Cohen IS, Goldberg ME. The proprioceptive representation of eye position in monkey primary somatosensory cortex. *Nat Neurosci.* 2007;10:640-646.
31. Lukas J-R, Blumer R, Denk M, et al. Innervated myotendinous cylinders in human extraocular muscles. *Invest Ophthalmol Vis Sci.* 2000;41:2422-2431.
32. Hertle RW, Chan C, Galita DA, Maybodi M, Crawford MA. Neuroanatomy of the extraocular muscle tendon enthesis in macaque, normal human and patients with congenital nystagmus. *J AAPOS.* 2002;6:319-327.

The correct answer to *What's Your Diagnosis?* is Smith–Lemli–Opitz syndrome.

REFERENCES

1. Smith DW, Lemli L, Opitz JM. A newly recognized syndrome of multiple congenital anomalies. *J Pediatr.* 1964;64:210-217.
2. Gold JD, Pfaffenbach DD. Ocular abnormalities in the Smith-Lemli-Opitz syndrome. *J Pediatr Ophthalmol.* 1975;12:228-233.
3. Tint GS, Irons M, Elias ER, et al. Defective cholesterol biosynthesis associated with the Smith-Lemli-Opitz syndrome. *N Engl J Med.* 1994;330:107-113.