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Securing extraocular muscles in strabismus surgery: biomechanical analysis of muscle imbrication and knot tying technique

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An experimental study was performed to quantitatively evaluate the tensile strength implications of two important steps in extraocular muscle surgery: muscle imbrication and knot configuration. The study was conducted in a controlled fashion using fresh ex vivo pig eyes with extraocular muscles attached and a precision digital force gauge. The study provides clinically translatable data to inform optimal surgical technique. The results suggest that imbrication of the muscle edge is most secure when the suture is looped around itself in a manner that allows it to be tightly cinched and locked and that granny knots possess similar tensile strength to square knots.

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Strabismus surgery requires a strategy to secure extraocular muscles to sclera until adequate scarring develops. There are several possible points of failure, including the suture thread, the scleral fibers, the imbrication of the muscle by the suture, and the surgical knot itself. Prior studies have addressed the maximum forces generated by extraocular muscles[1] and the time course of healing between a reattached muscle and sclera.[2-6] A series of recent studies has also evaluated the tensile characteristics of the sclera,[7] the position of the imbricating suture,[8] and various aspects of the suture itself.[9] The current study was performed to objectively address two additional yet important aspects of surgical technique related to extraocular muscle reattachment, for which biomechanical data is lacking: imbrication technique and configuration of the surgical knot. The purpose of these studies is to facilitate surgical decisions that are evidence based in order to optimize surgical efficiency and success.

Methods

Fresh pig eyes (n = 5 per imbrication technique) were mounted in a model styrofoam orbit, and medial rectus extraocular muscles were identified and dissected free of surrounding connective tissues. A double-armed 6-0 polyglactin 910 suture (Vicryl, Ethicon Inc, Sommerville, NJ) on an S-14 spatula needle was passed partial thickness from the center of the muscle to each edge, 2 mm posterior to the cut edge. This was followed by full-thickness passes 2 mm central to the muscle edge. The imbrications were completed and tightened using two distinct techniques. In the first the leading end of the thread was pulled directly between the partial and full-thickness passes without forming a loop (Figure 1). In the second, the leading end of the thread was pulled under and over the partial-thickness pass in order to form a knot-like loop configuration that would lock down and resist loosening (Figure 1). The ends of the suture were pulled to tighten the imbrications and then connected to the transducer of a precision digital force gauge (Chattilon-Ametek, model DFS2-010, Largo, FL). Longitudinal tension on the sutures was gradually increased until rupture occurred. In a second set of experiments two strands of 6-0 Vicryl suture were tied in a 2-1-1 knot (ie, a double throw followed by two single throws), using either a square knot or granny knot configuration (Figure 2). The strands were then secured and traction applied until rupture occurred.

Differences in mean rupture values between groups (n = 5 per group) were compared using a *t* test (two-tailed).

Results

Since rectus extraocular muscle contraction in humans is known to produce forces up to 100 g, it is reasonable to seek at least 100 g of support from every component of

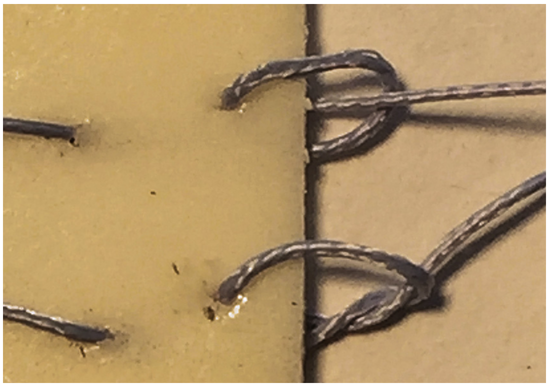

FIG 1. Photographs demonstrating the thread configuration of an imbricating stitch that either forms a nonlocking (top) or locking (bottom) loop. To improve clarity the thread shown is 2-0 polyester.

FIG 2. Photographs showing the configuration of a 2-1-1 square knot (top) or granny knot (bottom). To improve clarity the thread shown is 2-0 polyester.

the attachment until healing occurs. Previous studies have shown that a knotted 6-0 Vicryl suture and 2 mm scleral tunnels of 10%-20% depth each provide tensile strengths in excess of 300 g[7,9] and are therefore unlikely to be sources of failure leading to a slipped or lost muscle. Prior studies have also shown that muscle imbrication should performed >1 mm from the cut edge and >1 mm from the lateral edge to ensure adequate tensile strength.[8]

The data in this study revealed that either imbrication technique was effective in creating imbrications that held in excess of 100 g of tension (Table 1). However, the locking technique was significantly stronger than the nonlocking technique. This result was not unexpected, given that the locking technique securely incorporates the imbricated muscle fibers, whereas the nonlocking technique does not. Although the difference may not be clinically significant, given that either technique provides tensile strength far in excess of 100 g, it would seem preferable to choose the locking configuration achieving the highest strength possible.

Table 1. Mean tensile strengths

Technique	Tensile strength, g, mean ± SD	*P* value
Locking imbrication	888 ± 256	0.03
Nonlocking imbrication	483 ± 94	
Square knot	336 ± 56	0.59
Granny knot	360 ± 50	

The data also showed that the square knot had equivalent tensile strength to the granny knot (Table 1). In each case the thread rutured at the base of the knot, and in no case did the knot itself unravel. This result suggests that either knot configuration is acceptable surgically for securing extraocular muscles and that a square knot configuration is not critical to secure muscle reattachment. Given that these studies were performed with 6-0 Vicryl, however, the data cannot necessarily be extrapolated to other thread compositions or gauges.

These studies were performed in a relatively nontendinous part of the muscle, which is more reflective of the tissue enountered in resections than recessions. Although it is unlikely that the relative tensile relationships related to imbrication techique would be significantly altered by performing the study on more tendinous tissue, the current data do not allow a definitive conclusion in this regard. In addition, the use of postmortem tissue likely resulted in reduced integrity of the muscle tissue, making the tensile values lower than they would have likely been in vivo. However, this artifact does not change the relative differences between imbrication techniques.

The data collected in this study provide useful information that may help in understanding the biomechanical implications of imbrication technique and surgical knot configuration in strabismus surgery. The data show that the tensile strengths afforded by the two imbrication configurations are sufficient to meet the biomechanical requirements of standard strabismus surgery, but there is a significant mechanical advantage when a locking imbrication is performed. In terms of knot strength, no difference was found between granny knots and square knots using 6-0 Vicryl, in spite of the customary teaching that square knots are prefered for their superior strength.

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Retinal astrocytoma in a young male with PTEN hamartoma tumor syndrome

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We present the novel finding of retinal astrocytoma in a 15-year-old boy with phosphatase and tensin homologue hamartoma tumor syndrome, confirmed by genetic testing.

Case Report

A 15-year-old boy with a history of phosphatase and tensin homologue (PTEN) hamartoma syndrome and type 1 myotonic dystrophy without significant ocular history was referred to pediatric ophthalmology at Rhode Island Hospital. Known systemic manifestations of his disease included autism, macrocephaly, gastrointestinal juvenile polyps, and penile freckling. PTEN hamartoma tumor syndrome (PHTS) was suspected when he passed a polyp with histology showing juvenile polyp. Sequencing and deletion/duplication analysis of the *PTEN* gene showed a heterozygous deletion of the entire gene, leading to the diagnosis. Small nucleotide polymorphism microarray was performed subsequently to determine the breakpoints and revealed a 151 Kb deletion at 10q23.2q23.31 [chr10: 89,480,314-89,631,525; GRCh37/hg19] overlapping *PTEN* and Killin (*KLLN*) genes. Given normal physical examination findings of both parents, the deletion was deemed to be de novo, and parental genetic testing was deferred. In the setting of known myotonic dystrophy, which had been diagnosed prenatally due to the family history in the mother, he was referred to pediatric ophthalmology to rule out presence of cataracts.

Ocular examination revealed 20/20 vision in both eyes, normal intraocular pressure, and no afferent pupillary defect. Anterior segment examination was unremarkable. Retinal examination of the right eye revealed blurred disk margins and a golden, mulberry-like retinal lesion approximately 1 disk diameter in size overlying the inferotemporal vasculature (Figure 1). Fundus examination of the left eye was unremarkable.

He was referred to a pediatric retina specialist. Macular ocular coherence tomography (OCT) showed moderate parafoveal thickening, with normal foveal contour in both eyes (Figure 2A). B-scan ultrasonography revealed hyperechogenicity of the lesion (Figure 2B). Given the lesion's appearance, the diagnosis of retinal astrocytoma was made. Ocular examination remained unchanged 2 years later.

Discussion

PTEN is a tumor suppressor protein in the PI3K/PTEN/AKT/TSC/mTORC1 signaling pathway, encoded by the *PTEN* gene that, when mutated, overactivates the AKT pathway, promotes cell growth, and predisposes individuals to a spectrum of abnormalities collectively referred to as PHTS. Subdivisions of this disorder include Cowden and Bannayan-Riley-Ruvalcaba syndromes. Numerous systemic abnormalities are associated with PHTS, including macrocephaly, autism and developmental delay, benign and malignant tumors of the skin, thyroid, breast/endometrium, and gastrointestinal tract, penile freckling, and arteriovenous malformations/hemangiomas.[1] Identification of a heterozygous mutation of the *PTEN* gene establishes the diagnosis.[1]

Reported ophthalmic manifestations include: amblyopia, strabismus, myopia, downward-slanting palpebral fissures, corneal nerve hypertrophy, prominent Schwalbe lines, cataract, pseudopapilledema, angioid streaks, and retinal hemangioma. These manifestations are not specifically found to demonstrate a genetic subcategory within PHTS but rather were isolated findings among PHTS patients. This demonstrates the variety of pathology that can

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