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The Effect of the Epitendinous Suture on Gliding in a Cadaveric Model of Zone II Flexor Tendon Repair

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Abstract

INTRODUCTION—Zone II flexor tendon lacerations are complicated by adhesion formation, tendon ruptures and triggering, often leading to compromised results. Size, type of suture, number of strands, knots and epitendinous suture can affect repairs rendering them bulky and inhibit tendon gliding by increasing friction. We hypothesized that increasing core sutures (to six from four) may be preferable in terms of gliding coefficient (GC) measurements when compared to adding an epitendinous suture. It has been stated in the literature that the epitendinous suture donates critical strength to the repair of flexor tendons in zone II. We hypothesized that the inclusion of epitendinous suture in two standard repairs would contribute negatively to the gliding coefficient of the repaired tendon unit.

MATERIALS AND METHODS—Nineteen fresh-frozen cadaveric fingers were utilized for testing. We compared a control group (dissected digits without repair) and 4-strand or 6-strand core tendon repairs both with and without epitendinous suture. Arc of motion was driven by direct loading and digital images were acquired and analyzed. Outcomes were defined as the difference in gliding coefficient between the native uninjured and repaired state at each load. A linear mixed-model analysis was performed with comparisons between repairs to evaluate the statistically relevant differences between groups.

RESULTS—The test of fixed effects in the linear model revealed that repair type, and the use of epitendinous suture significantly affected the change in gliding coefficient. The addition of an epitendinous suture produced a significant decrement in gliding regardless of repair type.

CONCLUSION—There was significant improvement in gliding coefficient with the omission of the epitendinous suture in both repair types (four or six-strand).

Keywords

Epitendinous suture; gliding coefficient; zone II flexor tendon repair

INTRODUCTION

Treatment of zone II flexor tendon injuries remain a challenging clinical problem, with poor to fair results in 7–20% of patients. Complications include decreased range of motion secondary to adhesion formation, joint contractures, tendon ruptures, triggering, tendon abrasion, and pulley failure [1–3].

A strong repair that enables early motion and resists gap formation is the goal of treatment. Early motion is an important contributor to outcome and gap formation can lead to decreased strength [1, 2, 4]. Repairs typically include a core suture of 3-0 or 4-0 nonabsorbable polyfilament material [2, 4, 5, 6, 7], with at least 4 strands crossing the repair site [8, 9, 10], locking suture technique [11, 12, 13, 14], and limited knots at junction sites [4, 15, 16]. Some studies have advocated the use of peripheral epitendinous suture to enhance repair strength [17, 18, 19]. However, multiple core strands and addition of an epitendinous suture may increase bulk and thus lead to triggering [20, 21] and an increase in friction of the tendon as it passes through a pulley [1, 21, 22].

The consequences of bulky repairs have motivated numerous techniques to quantify smooth gliding [1, 4, 23, 21]. The Gliding Resistance (GR) model determines the friction force at the tendon-pulley interface as measured with load transducers [22, 24], thereby measuring surface interactions without taking into account the overall finger function or the effect of adhesion formation. Gliding resistance also only allows for the tendon to be tested in one joint configuration [22]. Work of flexion (WOF) models are designed to account for inhibitors to tendon gliding, adhesions, and joint stiffness which all contribute to the force required for finger flexion after injury and repair [21, 22, 24, 25]. However, traditional WOF models fail to separate work into that generated by the tendon-pulley unit and the work induced by outside factors (e.g., joint stiffness) [24].

In animal studies, the quantitative measurement of increases in tendon-gliding resistance has been termed the gliding coefficient [26]. By utilizing the control for its normative data, the gliding coefficient allows the isolation of the changes in WOF caused by the flexor tendon repair. This method alone has the advantage of easily identifying outlying or erroneous measurements such as those generated by an error in determining the neutral position and flexion angles over a range of applied loads [12]. The gliding coefficient of friction has not been studied to our knowledge in the cadaveric human zone II flexor tendon model except in our previous work [36].

We hypothesized that the use of an epitendinous suture would have a negative effect on gliding coefficient. We further hypothesized that when viewed from the standpoint of the change in gliding coefficient caused by placing an epitendinous suture, the detriment to gliding would be present with either a standard four or six strand core suture repair.

MATERIALS AND METHODS

After appropriate institutional review board exemption, seven fresh-frozen cadaver forearm specimens were obtained from the anatomical gifts program. The specimens had no history of prior surgery, and no history of pathology to the upper extremity. The index, long, and

ring fingers were chosen for experimentation. A total of 19 fingers were used in the study with the remaining two digits used to the technique and perfect the apparatus design.

The forearm was secured using spanning external fixation (Synthes, Paoli, PA) dorsally from the proximal radius to the 3rd metacarpal midshaft with the wrist in neutral position. The proximal radioulnar joint was secured to prevent rotation of the forearm. The thumb and small finger were removed. The forearms were dissected at the level of the musculotendinous junction to identify the flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) tendons associated with each digit. The proximal ends of the tendons associated with each digit were then secured together and attached to a small S shaped hook for testing purposes.

Using a volar approach to the digit, the FDS and FDP tendons as well as the A1 and A2 pulleys were identified. Care was taken to not disrupt cruciates or other pulleys in an attempt to preserve as much of the native tissue as possible. The metacarpophlangeal (MCP) joint of each finger was secured using kirschner wires (Synthes, Paoli, PA) in 30 degrees of flexion in order to ensure the proximal interphalangeal (PIP) and distal interphalangeal (DIP) angles were measured without confounding measurements. A single screw was passed through the 2nd, 3rd, 4th and 5th metacarpal heads to prevent any flexion of digits relative to each other at the carpometacarpal level. The specimens were kept moist with frequent bathing in phosphate buffered saline solution.

Testing Apparatus

The specimen with the external fixator was mounted on a ring stand such that the fingers were allowed to extend freely [Figure 1]. The external force application pulley system consisted of two pulleys (P1 and P2) suspended from a modified ring stand. P1 was in line with the flexor tendon. P2 was placed along the same axis as P1 but further from the specimen to allow for graded loading. To flex the experimental digit through the full arc of motion, the associated flexor tendons were loaded in the direction of the anatomic pull in 50 gram standardized weights-increments to load the tendons in the range between 0 and 700 grams. With every increment of the load, digital sagittal images of the specimens were captured. The PIP joint flexion angles at every loading increment was measured from the digital images using ImageJ software (imagej.nih.gov). The measured flexion angles were plotted against the applied load. To quantify the resistance to flexion due to adhesions, the flexion data were fitted using nonlinear regression (Prism, GraphPad Software, Inc.; La Jolla, California) to a single-phase exponential association equation of the form: *PIP Flexion angle* = $FA_{max} \times [1 - \exp(-m/GC)]$, where FA_{max} is the maximum PIP flexion angle and m is the applied load, as described previously [24].

The Gliding Coefficient (GC), which regulates the rate of rise of the flexion curve or the ease with which the flexion angle changes with increased loading was determined by nonlinear regression as a measure of the resistance to PIP joint flexion due to adhesions. We did not use load transducers as they are not used in the assessment of gliding coefficient. Gliding coefficient is measured using predetermined load scales.

Testing groups

All digits were used as their own internal controls and no finger was tested prior to open exposure of the pulleys. All digits underwent testing in the same positions and with the same set of pre-determined loads as in previous work [24, 36].

The FDP tendon was identified and lacerated at the distal most aspect of the A2 pulley with all specimens in full extension after testing in the native uninjured state (designated as “control”). At that point, one of two repairs took place. Either the tendon was repaired using the Indiana technique (using 4-0 Fiberwire suture, Arthrex, Naples, Florida) or the 6 strand looped suture repair technique described by Lim-Tsai (using 4-0 fiberloop suture, Arthrex, Naples, Florida) (FIGURES 2, 3) [27, 28, 29, 30]. The final group incorporated a running, locking 6-0 Prolene epitendinous suture described by Lin et al, in addition to the FDP repair (FIGURE 4) [31].

The testing groups were designated as control (dissected digit without tendon repair); FDP repair (4 or 6 strand); FDP repair with epitendinous suture (4 or 6 strand). Repairs were performed on all specimens (nine digits 4 strand and 10 digits 6 strand, two additional digits were used to practice the protocol for each condition for a total of 21 cadaveric specimens used in this study).

Analysis

Digital images of the finger of interest were analyzed using ImageJ Software (imagej.nih.gov). For each image, three independent blinded observers (ZY, CE, and SS) measured the angle at the PIP joint for all trials. [24]

Statistical Methods

Our sample size needs were based on earlier work by Yang et al., who found effect sizes of interest to range from 0.6–0.9 for most comparisons of glide coefficients [38]. Our study design was based on this work with measurements made at 14 different loads, and allowing 10 fingers per group for the 4 vs. 6 strand comparison. Even with a conservative expected effect of .6 [37], with $\alpha=0.05$ and estimated correlation of 0.10 between fingers from the same arm, we had 91% power to detect that difference. Although not the basis of our original calculations, a reduction to 9 fingers in the 4-strand group (while maintaining 10 fingers in the 6 strand group) reduced power to 88%.

The gliding coefficient of the experimental conditions (epitendinous vs. no epitendinous, 4 strand vs. 6 strand) were assessed relative to the control gliding coefficient value. Each condition was evaluated at varied loads multiple times by three independent blinded graders. The outcome measure was difference in gliding coefficient for each digit (of the repair minus the uninjured control value at each given load). A linear mixed model was used to determine the intraclass correlation coefficient (ICC) to measure agreement among the three graders.

Gliding coefficient change was defined as the least square mean differences in the measured gliding coefficient (repair minus control). These gliding coefficient changes were compared and standard errors were adjusted for all the information in the model [load used to flex the

digit, repair type, epitendinous suture as well as possible interactions between these variables]. The unit of observation was the finger, which was repeatedly measured by graders at different loads. This analysis allows the analysis of multiple observations gleaned independently by blinded observers on individual digits. No adjustments for multiple comparisons were made. All analyses were carried out using SAS/STAT software, Version 9.3 of the SAS System (Copyright © July, 2011, SAS Institute Inc) on a Windows 7 platform.

RESULTS

The ICC for grader agreement was 0.82 (95% CL=0.80–0.84). Gliding coefficient change is the difference in gliding coefficient for the repaired tendon minus the gliding coefficient for the native uninjured tendon. Negative values reflect poorer gliding for repair when compared to the corresponding control uninjured tendon. The gliding coefficient change for a four stranded repair was -4.76 (SEM 1.99) and the gliding coefficient change for a six stranded repair was 1.09 (SEM 1.94). This indicated that in our hands, poorer gliding was seen with the four stranded repairs than the six stranded repairs overall and this difference was significant ($p=0.0014$).

The inclusion of an epitendinous suture in the repair exerted a statistically significant negative impact on gliding regardless of repair type. The gliding coefficient change for a four stranded repair with the epitendinous suture (repair with epitendinous suture minus repair without the epitendinous suture) was -1.3 (SEM=2.04, $p=0.0534$). The gliding coefficient change for a six stranded repair with epitendinous suture (repair with epitendinous suture minus repair without the epitendinous suture) was -2.04 (SEM=2.00, $p=0.0145$).

The test of the main effects in the linear statistical model revealed only repair type (4 stand vs. 6 strand) (estimate= -5.8527 , se= 1.7871 , $p=0.0011$), and absence vs. presence of epitendinous suture (estimate= -1.8618 , se= 0.6026 , $p=0.0020$) significantly affected the gliding coefficient. However the interaction of repair with epitendinous suture did not significantly affect the gliding coefficient ($p=0.7652$).

DISCUSSION

Our study is a variation on the previously designed work of flexion model [23, 26] to determine the gliding coefficient of friction between two types of repairs and the addition of an epitendinous suture. The model takes into account joint stiffness, inhibitors to tendon gliding, soft tissue characteristics and allows for a true comparison of different interventions to a native untouched tendon in a free standing model. By measuring the change in gliding coefficient with a change in tendon repair, we can speak directly to the effect each disturbance has on gliding. This measurement does require optical analysis of the precise change in digit position under a given tendon load, it does not depend in any way on the use of force transducers of any kind.

The addition of an epitendinous suture to either a four or six strand repair significantly decreased gliding. This could be a reflection of the increased force needed to overcome the

bulkiness of the repair or the added bulk of the epitendinous suture material itself. The added bulk could lead to catching and triggering which could lead to limitations in digital motion in the clinical setting. Our data noted these changes independent of repair type.

A decrease in gliding coefficient, thus increase in friction, requires a greater amount of force to initiate motion and might result in an increased risk of peritendinous adhesion formation or failure at the repair site [22, 26, 32]. Taken together, these data highlight a potentially greater negative effect on gliding coefficient in this model attributable to the epitendinous suture and this effect may have consequences, which are only evident in the living patient.

Osei et al recently demonstrated in an ex-vivo model, 8 strand repairs using 4-0 looped polyfilament suture produced a greater maximum load to failure when compared to 4 strand repairs with 4-0 non-looped polyfilament. While they measured the size of their repairs and found them to be similar in all groups, they could not evaluate gliding or friction. They also did not include epitendinous sutures in their model. [35] This is particularly relevant as it provides a basis for the looped repair used in our technique and may support the suggestion that more strands contribute more strength. Most importantly, in their study, the size of repair did not depend critically on the number of strands. This finding may be an explanation for why our six stranded repairs, performed with looped suture as in their study, did not produce as much impairment in gliding as a standard four-strand repair. Their data also dispels the assertion that fewer strands always result in less bulk. We believe that bulk relates to gliding but may not depend directly on the number of strands alone.

Vigler et al reported differences in work of flexion comparing two types of repairs however their study dissected a significant amount of soft tissue to separate the FDP from all pulleys and cruciate systems, with the exception of A2, as well as secure the FDS so as to not interfere with their measurements [22]. Their design, while demonstrating one repair was superior to the other was not a true model to examine work of flexion. Instead, Vigler et al provide a measurement of the change in work of the remaining digit only as a single unit at the pulley and repair interface. The model therefore does not take into account work from outside factors.

To our knowledge, this study is the first to examine the actual work of flexion of the entire digit for the question of the additional bulk of the epitendinous suture per se.

There are many limitations to our study. First, we chose only two repair techniques to test the addition of epitendinous suture. Perhaps the addition of still more techniques chosen for their low friction would demonstrate little effect of the epitendinous suture. One counterargument to this theoretical concern is that each of our two techniques [27, 28, 29], showed significantly poorer gliding with the addition of epitendinous suture despite different gliding profiles without epitendinous suture. Second, we have only tested one method of epitendinous suture configuration. We chose a common configuration of epitendinous suture to make the experiment more uniform and allow the maximum possible benefit of the addition of this suture. If the purpose of epitendinous suture is to gather stray ends of the repair and lower bulk and increase strength then the chosen suture should have shown improvement in at least one of the chosen core suture configurations. In practice, it

worsened gliding in both groups. Third, we have used the minimum number of digits allowable to make an appropriately powered statement about the effect of epitendinous suture. If the addition of epitendinous suture is indeed quite critical to the overall ultimate strength of the repair, then we are not powered to show that effect on ultimate strength and we did not measure the ultimate strength of the repairs in our samples. Several studies have shown that the strength of repair is dependent, in part, upon the number of core suture strands [1, 2, 4, 6, 33, 34, 35]. Our study demonstrates that there was a significant impairment of gliding of the tendon in the 4 strand repair when compared to the 6 strand repair which we can only explain using the findings of Osei et al [35]. Although this study is not designed to test the overall strength of repair, our findings suggest that even without the addition of epitendinous suture, repairs with more strands do not necessarily have poorer gliding. We do not explore this further to prove that our six stranded repairs are stronger in our hands. This is because of our study design which included further measurements which require the repair to remain intact. Fourth, we did not investigate the effect of looped suture on the bulk of repair and as such it could be that the six strand repair used in this comparison has better gliding because of the looped nature of the suture. Nonetheless, we feel the use of the 6 and 4 strand repairs in this work is appropriate because both are standard repairs used in our practice and the practice of many others [27, 28, 30]. Fifth, is the limitation conferred by the all cadaveric studies in the area of direct clinical applicability. We cannot say definitively what the measured effect of epitendinous suture is in the living human in terms of clinical results. We cannot simulate either healing or adhesion formation in this model. It could be that the added bulk of epitendinous suture is somehow less significant than the differences in bulk attributable to the repair technique. Finally, it could be that there are technical aspects of each repair technique which transcend strand number in terms of importance to gliding. Although there may be no way to correct for this, we tried to the best of our ability to simulate repairs which we perform in actual humans and achieved a fairly low variability in terms of gliding within groups.

Our study showed that the addition of epitendinous suture statistically significantly affected the gliding coefficient and resulted in decreased gliding through the pulley in both a standard 4 and 6 strand repair. In the clinical setting, this may correspond with an expected increase in catching or triggering. The epitendinous suture used in this model reliably exerted a negative effect on gliding, whereas extra core suture number, per se, did not.

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Clinical Relevance

The epitendinous suture used in this model resulted in poorer gliding of the repair which may correspond with an expected increase in catching or triggering.

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FIGURE 1.

The experimental setup. The tendons were tethered together proximally and the force directed in line with the tendons. Two pulleys were used to create as low a friction set up as possible. m represents the weight.

FIGURE 2.
The 4 strand Indiana repair technique.

FIGURE 3.
The Lim and Tsai using 4-0 fiberloop suture.

FIGURE 4.

The running locked epitendinous suture described by Lin et al.¹⁸