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The Effects of Oblique or Transverse Partial Excision of the A2 Pulley on Gliding Resistance During Cyclic Motion Following Zone II Flexor Digitorum Profundus Repair in a Cadaveric Model

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Abstract

Purpose—To compare the gliding resistance of flexor tendons after oblique versus transverse partial excision of the A2 pulley in a human cadaveric model, to determine the effect of the angle of pulley trimming.

Methods—We obtained 36 human flexor digitorum profundus tendons from the index through the little finger and repaired them with a modified Massachusetts General Hospital suture using 4-0 FiberWire. We repaired all tendons with a similar epitendinous stitch. We randomly assigned the tendons to 1 of 3 groups: intact pulley, transverse partial excision, or oblique partial excision. We measured peak and normalized peak gliding resistance between the repairs and the A2 pulley during 1,000 cycles of simulated motion.

Results—There was no significant difference in the peak or normalized peak gliding resistance at any cycle among the 3 groups.

Conclusions—Both transverse and oblique trimming of the A2 pulley had similar effects on the peak and normalized gliding resistance after flexor tendon repair.

Clinical relevance—When partial pulley resection is needed after flexor tendon repair, the transverse or oblique trimming of pulley edge does not affect repaired tendon gliding resistance.

Keywords

Flexor tendon; pulley; repair; friction

Flexor tendon repair in the fingers is challenging.^{1–3} Digital pulleys are often injured with flexor tendon injury. The pulley system is essential for precise tracking of the tendon and to prevent bowstringing. Partial release, venting (incomplete incision of a major pulley) the sheath laterally, and creating a pulley plasty are known to improve tendon gliding.^{4–6} Tanaka et al⁷ reported that partial excision (distal 50%) of the A2 did not increase gliding resistance and retained substantial pulley strength. However, Kutsumi et al⁸ reported increased gliding resistance after flexor pollicis longus repair and transverse partial excision of the oblique pulley, but not with oblique excision. Based on these results, we hypothesized that oblique partial excision of the A2 pulley would reduce gliding resistance after flexor tendon repair. Therefore, the purpose of this cadaveric study was to compare the gliding

resistance of flexor tendons after oblique versus transverse partial excision of the A2 pulley in a human cadaveric model.

MATERIALS AND METHODS

Specimen preparation

We obtained 36 fresh-frozen fingers from 9 index, 9 middle, 9 ring, and 9 little fingers of 13 human cadavers. There were 6 men and 7 women, with an average age of 70 years (range, 26–91 y). Our institutional review board approved this study. We amputated fingers at the metacarpophalangeal joint level. We approached flexor digitorum profundus (FDP) tendons through a transverse incision in the flexor sheath, just distal to the A2 pulley. We marked the tendons at the distal end of the A2 pulley at both full extension and full flexion. We connected a 4.9-N load (ie, a 500-g weight) to the proximal FDP tendon to maintain tendon tension. The distance between the 2 marks was considered to represent the normal movement of the FDP tendon (Fig. 1).

After we measured gliding resistance in the intact tendons (see method below), we made a transverse laceration in the FDP 12 mm distal to the proximal FDP tendon mark. We chose this level of laceration to optimize repair site movement through the pulley system while testing. The laceration level was distal to the A2 pulley, and thus it was possible to perform the repair without incising the pulley.

We repaired all FDP tendons with a 4-0 FiberWire (Arthrex, Naples, FL) modified Massachusetts General Hospital suture (Fig. 2). All repairs also included a simple continuous epitendinous suture using 6-0 Prolene (Ethicon, Somerville, NJ). The simple running epitendinous throws were approximately 2 mm from the lacerated tendon ends, with 1 mm between each throw. The number of throws varied from 12 to 16, determined by the tendon size. We tied all core and epitendinous suture knots with 4 square knots. We set the tension of all of the core and epitendinous sutures to coapt without causing bunching at the repair site. To limit variability, the same investigator (T.M.) performed all repairs. We kept the A1 pulleys, A2 pulleys, and FDS tendons intact during the experiment.

Measurement of frictional force

We measured the friction between tendon and pulley using a standard method.⁹ We preserved both proximal and middle phalanges, A1 pulley, A2 pulley, flexor digitorum superficialis (FDS), the A2 pulley parietal membrane, and the FDP visceral membrane. We fixed the proximal interphalangeal joint with a Kirschner wire in full extension. We affixed each specimen on the custom testing device with the palmar side upward (Fig. 3). To maintain proper tension on the FDS tendon, we attached a 2-N load (100-g weight) to its proximal end. We determined the magnitude of this load based on prior *in vivo* tendon research, to reproduce the load experienced by normal tendons *in situ*.^{10,11} The testing system consisted of 1 mechanical pulley, 1 mechanical actuator with a linear potentiometer, and 2 tensile load transducers. To simulate passive mobilization, we connected the distal transducer to a 4.9-N load.^{10,11} The proximal load transducer was attached to the mechanical actuator.

Based on previous studies from our laboratory, we set a 50° arc of contact, 30° and 20° between the horizontal plane and the proximal and distal transducer cables, respectively, to provide precise gliding resistance measurements.^{12,13} For each cycle, the actuator pulled the tendon proximally against the 4.9-N load at a rate of 2 mm/s. We restricted excursion to the expanse between the 2 FDP tendon markers, therefore producing tendon movement from full finger flexion to full finger extension. We recorded the forces at both proximal and

distal tendon ends over the tendon movement. We kept tendons moist during testing by submerging them in a saline bath. The force between the proximal and distal tendon ends denoted the gliding resistance. We measured the peak gliding resistance between intact or repaired FDP tendon and intact or partially excised A2 pulley, and normalized data by dividing the after-repair by the pre-repair gliding resistance.

We initially recorded the gliding resistance for the intact FDP tendon with the intact A2 pulley for pre-repair. We then cut and repaired the tendon and recorded the post-repair gliding resistance. After post-repair measurements, we randomly placed fingers into 3 different groups, with 3 index, 3 middle, 3 ring, and 3 little fingers in each group. In the second group (transverse excision), we measured the A2 pulley width at the palmar aspect and marked 50% of the pulley length with calipers. We transversely excised the distal 50% of the A2 pulley (Fig. 4A). In the third group (oblique excision), an oblique excision removed 50% of the distal and 50% of the A2 pulley (Fig. 4B). We recorded the gliding resistance of each group after 1 cycle, then after every 50 cycles up to 500 cycles, and then after every 100 cycles up to 1,000 cycles of tendon motion, as described above. We then normalized these data by dividing the peak gliding resistance of each repaired tendon at the various cycles by the peak gliding resistance of that tendon in the intact, normal state.

Statistical analysis

The mean gliding resistance of the human FDP tendon before and after modified Massachusetts General Hospital repair with 4-0 FiberWire was 0.26 and 1.50 N, respectively, with standard deviations of 0.10 and 0.30 N.¹⁴ Using these data as a guide, with a sample size of 10 we would have 80% power at a significance level of $P < .05$ to detect a difference in gliding resistance of 0.25 N. This difference represents a 20% decrease, which we thought could be clinically relevant.

We chose 1-factor analysis of variance followed by the Tukey-Kramer post hoc test for analyzing variables. Results are expressed as means $\pm$ standard deviation. We set the statistical significance threshold at $\alpha = 0.05$.

RESULTS

Tables 1 and 2 list the means and standard deviation of the peak gliding resistance and normalized gliding resistance.

The peak gliding resistance (Fig. 5) for the intact and repaired tendons is displayed in Figure 6, which shows the normalized results. For any given condition, there was no significant difference in either the peak or the normalized peak gliding resistance among the 3 groups. In each, there was no significant difference in either the peak or the normalized peak gliding resistance among any given after-repair condition.

DISCUSSION

Our results showed that both transverse and oblique excision of the A2 pulley resulted in similar peak and normalized gliding resistance after flexor tendon repair. Tanaka et al⁷ also reported that there was no significant difference in the peak gliding resistance of the repaired tendons between the intact A2 pulley and 50% transverse excision. We have now also shown that oblique excision of the A2 pulley yielded similar results. Kutsumi et al⁸ reported that in the case of the thumb oblique pulley, gliding resistance increased after transversely trimming and tendon repair. Based on this study, we expected that oblique excision of the A2 pulley would reduce the gliding resistance after flexor tendon repair in the finger. However, in our study, oblique excision of the A2 pulley did not reduce friction. The lack of

benefit may be related to the role of the FDS as a second sheath for FDP in the index through little digits.¹⁵ Thus, pulley trimming is less important in the fingers than it is in the thumb. In contrast, management of the FDS is important in managing gliding resistance after tendon repair. Zhao et al¹⁶ reported that by resecting 1 slip of the FDS tendon, gliding resistance decreased 47% and 35% when associated with Massachusetts General Hospital and modified Kessler repairs to the FDP, respectively.

There are limitations to this study. First, although we made every attempt to repair the tendons with similar tension, the repairs were handmade and thus may have varied slightly from each other. However, we believe that these effects should be random and not affect one study condition more than another. Second, we performed this study *in vitro*, and results may vary *in vivo*. The testing system was also nonphysiologic in that the tendon glided against a pulley instead of an intact digital sheath, and we used fixed angles to load the tendon. This process is unlike that in a natural human setting. We measured gliding resistance during 1,000 cycles of motion to simulate rehabilitation therapy, but in the clinical setting, changes associated with postoperative edema and healing might alter gliding resistance; we did not assess the effect of such changes in this cadaver study. Finally, in this study, our cadaver specimens had a mean age of 70 years. Although there might be differences in tendon gliding associated with age, in our opinion, these are likely to be dwarfed by the more substantial changes between the intact tendon and the repaired tendon.

The clinical implication of our findings is that A2 pulley trimming need not be transverse, at least with regard to its effect on gliding resistance. Pulley length may be partly preserved by oblique trimming if this seems clinically appropriate.

Acknowledgments

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FIGURE 1.
Testing specimen. The proximal and distal marks indicate the full range of motion.

FIGURE 2.
Schematic drawings of the modified Massachusetts General Hospital repair.

FIGURE 3.

Experimental setup and testing apparatus for the gliding resistance of the repaired tendon/pulley system. We mounted the specimen with repaired FDP tendon on the testing apparatus. (Reprinted with permission from Silva JM, Zhao C, An KN, Zobitz ME, Amadio PC. Gliding resistance and strength of composite sutures in human flexor digitorum profundus tendon repair: an in vitro biomechanical study. *J Hand Surg* 2009;34A:87–92.)

FIGURE 4. Testing groups. **A** Transverse excision of the A2 pulley. **B** Oblique excision of the A2 pulley.

FIGURE 5.

Peak gliding resistance of the FDP tendons in the 3 groups at different cycles of tendon motion. Arrows indicate where we performed the statistical analysis.

FIGURE 6.

Normalized to intact state peak gliding resistance of the FDP tendons in the 3 groups at different cycles of tendon motion. We divided after-repair peak gliding resistance by pre-repair peak gliding resistance for normalization. Arrows indicate where we performed the statistical analysis.

TABLE 1

Peak Gliding Resistance (Means $\pm$ SD)

A2 Pulley	Peak Gliding Resistance (N)				
	Before Repair	After Repair	At 1 Cycle (After Excision)	At 100 Cycles (After Excision)	At 1,000 Cycles (After Excision)
Intact	0.61 $\pm$ 0.19	2.96 $\pm$ 0.73		2.79 $\pm$ 0.71	2.61 $\pm$ 0.56
Transverse excision	0.60 $\pm$ 0.18	2.50 $\pm$ 0.62	2.70 $\pm$ 0.61	3.02 $\pm$ 0.84	2.90 $\pm$ 0.66
Oblique excision	0.69 $\pm$ 0.21	2.78 $\pm$ 0.93	2.80 $\pm$ 0.64	2.88 $\pm$ 0.59	2.83 $\pm$ 0.73

TABLE 2Normalized Peak Gliding Resistance (Means $\pm$ SD)

A2 Pulley	Normalized Peak Gliding Resistance (Ratio)			
	After Repair	At 1 Cycle (After Excision)	At 100 Cycles (After Excision)	At 1,000 Cycles (After Excision)
Intact	5.35 $\pm$ 2.19		4.96 $\pm$ 1.97	4.65 $\pm$ 1.69
Transverse excision	4.51 $\pm$ 1.69	4.95 $\pm$ 1.91	5.48 $\pm$ 2.11	5.17 $\pm$ 1.63
Oblique excision	4.28 $\pm$ 1.42	4.41 $\pm$ 1.57	4.48 $\pm$ 1.52	4.27 $\pm$ 0.99