Barbed Suture Tenorrhaphy: An Ex Vivo Biomechanical Analysis

Pranay M. Parikh, M.D.
Steven P. Davison, D.D.S., M.D.
James P. Higgins, M.D.

Washington, D.C.; and Baltimore, Md.

Background: Using barbed suture for flexor tenorrhaphy could permit knotless repair with tendon-barb adherence along the suture's entire length. The purpose of this study was to evaluate the tensile strength and repair-site profile of a technique of barbed suture tenorrhaphy.

Methods: Thirty-eight cadaveric flexor digitorum profundus tendons were randomized to polypropylene barbed suture repair in a knotless three-strand or six-strand configuration, or to unbarbed four-strand cruciate repair. For each repair, the authors recorded the repair site cross-sectional area before and after tenorrhaphy. Tendons were distracted to failure, and data regarding load at failure and mode of failure were recorded.

Results: The mean cross-sectional area ratio of control repairs was 1.5 ± 0.3, whereas that of three-strand and six-strand barbed repairs was 1.2 ± 0.2 ($p = 0.009$) and 1.2 ± 0.1 ($p = 0.005$), respectively. Mean load to failure of control repairs was 29 ± 7 N, whereas that of three-strand and six-strand barbed repairs was 36 ± 7 N ($p = 0.32$) and 88 ± 4 N ($p < 0.001$), respectively. All cruciate repairs failed by knot rupture or suture pullout, whereas barbed repairs failed by suture breakage in 13 of 14 repairs ($p < 0.001$).

Conclusions: In an ex vivo model of flexor tenorrhaphy, a three-strand barbed suture technique achieved tensile strength comparable to that of four-strand cruciate repairs and demonstrated significantly less repair-site bunching. A six-strand barbed suture technique demonstrated increased tensile strength compared with four-strand cruciate controls and significantly less repair-site bunching. Barbed suture repair may offer several advantages in flexor tenorrhaphy, and further in vivo testing is warranted. (*Plast. Reconstr. Surg.* 124: 1551, 2009.)

Achieving sufficient repair tensile strength to allow early passive and active motion is essential to functional rehabilitation and favorable outcomes following flexor tendon injury and repair.[1–8] Refinements in suture material[9–12] and the use of multistrand repair techniques[13–17] have nearly eliminated suture rupture as a cause of repair failure. Instead, inadequate suture-tendon interaction at the site of grasping or locking loops, and suture knot failure limit the tensile strength of current repairs.[14,18–21]

The notion of barbed suture tenorrhaphy was first conceived by McKenzie in 1967.[22] His original report demonstrated that repair with custom-fabricated, barbed 3-0 nylon suture could achieve a tensile strength of 17.8 to 26.7 N, equivalent to that of a two-strand Bunnell repair with G40 stainless steel wire. This repair allowed for excellent healing in canine flexor tendons after 5 weeks of immobilization. Since McKenzie's original report, no additional work has been published on this promising concept to address the potential role of barbed suture tenorrhaphy in the era of multistrand repairs and early active motion rehabilitation protocols demanding higher repair-site tensile strength. In 2006, the application of barbed

From the Department of Plastic Surgery, Georgetown University Hospital, and the Curtis National Hand Center, Union Memorial Hospital.

Received for publication June 28, 2008; accepted May 15, 2009.

Presented at the 87th Annual Meeting and Aesthetic Symposium of the American Association of Plastic Surgeons, in Boston, Massachusetts, April 5 through 8, 2008; and the 63rd Annual Meeting of the American Society for Surgery of the Hand, in Chicago, Illinois, September 18 through 20, 2008.

DOI: 10.1097/PRS.0b013e3181babb77

Disclosure: *The authors have no conflicts of interest to disclose.*

suture to expedite and more evenly distribute tension in skin closure was described by Murtha et al.[23] Their technique used modern, commercially available sutures, and allowed for knotless repair, with strength and wound healing equivalent to traditional suture technique.

To date, no current literature exists regarding the tensile strength of tenorrhaphy with modern barbed sutures. We hypothesize that such a suture could allow for knotless tendon repair with barb-tendon adherence along the entire suture length. In addition to improving tensile strength by eliminating knots and loops, such a technique may allow for decreased repair-site bunching. The purpose of this study was to evaluate the tensile strength and repair-site characteristics of a multistrand technique for flexor tenorrhaphy using barbed suture.

MATERIALS AND METHODS

Tendon Harvest and Preparation

Flexor digitorum profundus tendons from the index, long, and ring fingers of thawed fresh cadavers were harvested immediately before repair. The section of each tendon corresponding to zone II was identified and the center point of this area was marked. The cross-sectional area of the tendon was measured by a single observer at this point using an area micrometer. Tendons were then lacerated at this point with a scalpel, and desiccation was prevented during tendon harvest, preparation, repair, and testing with application of normal saline mist.

Tendon Repair

Each tendon was randomized to one of five repair groups. All repairs were performed immediately after laceration by a single surgeon (P.M.P.) under 2.5× loupe magnification. Tendons in the three control groups were repaired with the four-strand locked cruciate technique[24] using either 4-0 monofilament polypropylene suture (Prolene; Ethicon, Inc., Somerville, N.J.), 4-0 braided polyester suture (Ethibond; Ethicon), or 4-0 composite polyethylene and braided polyester suture (Fiberwire; Arthrex, Inc., Naples, Fla.). To evaluate the repair strength using core sutures alone, peripheral epitendinous repair was not performed.

All barbed suture repairs were performed using 2-0 bidirectional barbed polypropylene suture (Quill; Surgical Specialties Corp., Reading, Pa.) (Fig. 1), which has been demonstrated to have a tensile strength that most closely resembles that of

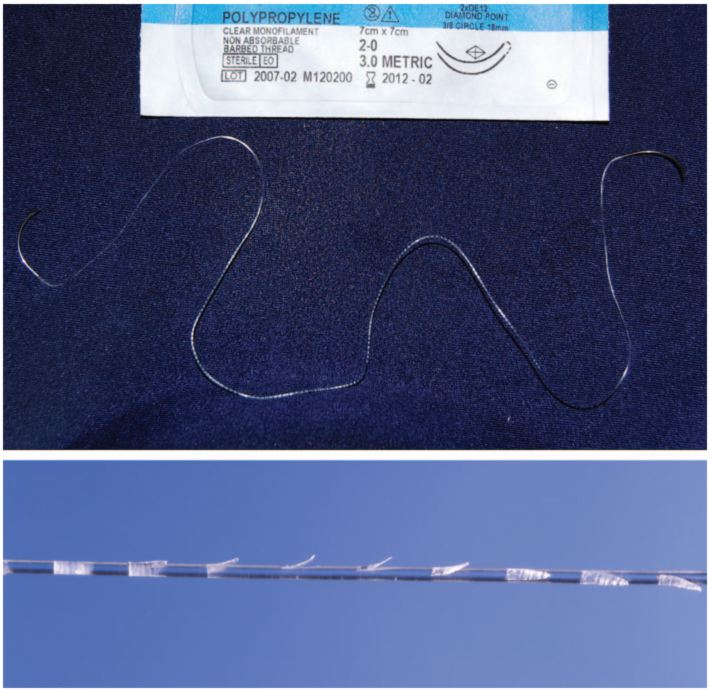

Fig. 1. (*Above*) 2-0 polypropylene barbed suture, double armed with 7-cm antiparallel barbed segments flanking 1-cm unbarbed segment at the midpoint. (*Below*) Close-up view of the barbed segment demonstrating barb orientation.

4-0 unbarbed suture.[25,26] Each barbed suture has a 1-cm segment of unbarbed monofilament at its midpoint, flanked by two 7-cm antiparallel barbed segments swaged onto 18-mm, 3/8 circle cutting needles.

The following technique was used for all barbed suture repairs (Fig. 2). One needle was passed anterograde into the distal tendon stump, and the other needle was passed retrograde into the proximal tendon stump. Each needle was advanced through the tendon, parallel to the direction of the fibrils, for a distance of 0.5 cm before exiting the tendon surface. Each end of the suture was then advanced to secure the unbarbed central 1 cm of suture in the repair site and approximate the tendon ends. Next, each needle was used to make two transverse passes at each tendon end, perpendicular to the direction of the tendon fibrils. Each needle was then reintroduced into the tendon and advanced parallel to the fibrils to traverse the injury site and enter the opposite end of the tendon. Again, two transverse passes were made to anchor the suture, and following the second pass, the excess suture and needles were cut off. This process resulted in a knotless repair with three strands crossing the injury site and four transverse passes at each end of the tenorrhaphy.

For six-strand barbed repairs, the three-strand technique described above was performed and then repeated with a second bidirectional barbed suture (Fig. 3). The cross-sectional area of each tendon at the repair site was measured and the ratio of the postrepair and prerepair cross-sectional areas was calculated.

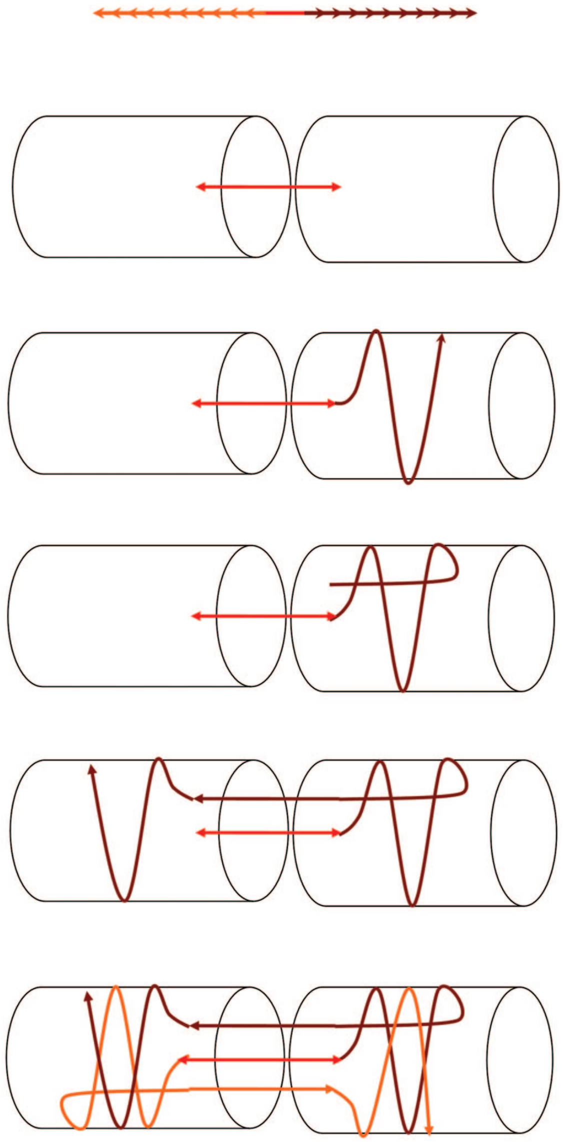

Fig. 2. (*Above*) Schematic of bidirectional barbed suture with central unbarbed segment (*red*) and opposing barbed segments (*orange* and *maroon*). (*Second row*) Central segment aligned in the gap between cut tendon ends. (*Third row*) First needle advanced through tendon, parallel to the direction of the fibrils, for a distance of 0.5 cm, and secured with two transverse passes perpendicular to the direction of the tendon fibrils. (*Fourth row*) Needle advanced parallel to the fibrils to cross injury site. (*Fifth row*) Two additional transverse passes made to anchor the suture. (*Below*) Process repeated with second needle in opposite end of tendon to complete symmetric knotless three-strand repair.

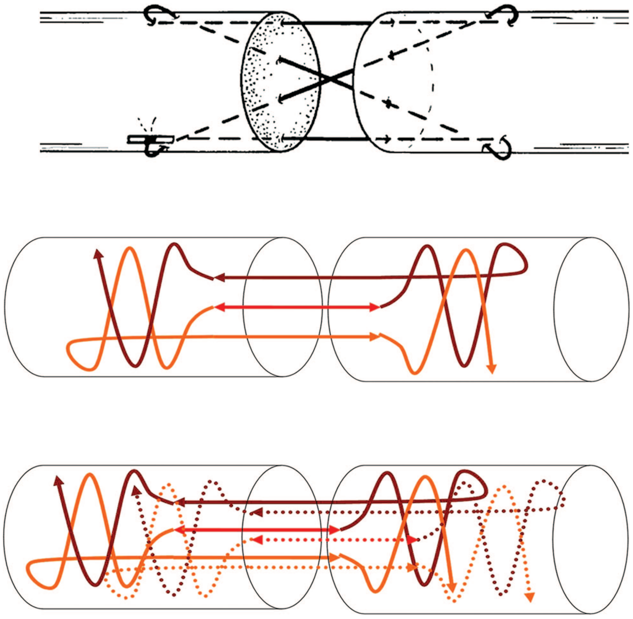

Fig. 3. (*Above*) Four-strand cruciate technique used for all control repairs. (*Center*) Three-core barbed technique demonstrating central unbarbed segment (*red*) with antiparallel barbed segments anchoring the suture into the tendon ends. (*Below*) Six-core barbed technique performed by repeating the three-strand technique with a second suture.

Biomechanical Testing

Repaired tendons were placed on a Mini-Bionix load cell (MTS Systems Corp., Eden Prairie, Minn.) with grasping clamps (pretested to ensure no tendon slippage with loads up to 500 N), preloaded to 2 N, and then linearly distracted at a rate of 50 mm/minute. Distraction parameters were chosen to exceed the forces experienced by the repair site during early active motion rehabilitation protocols.[27,28] Distraction continued until mechanical failure of the repair occurred, as defined by an abrupt drop in tensile strength or a visible gap of 3 mm. The load at failure was recorded. The failed repairs were then inspected under 4.0× loupe magnification to determine the mode of failure. Failures were categorized as suture breakage, knot rupture, or pullout when the suture and knot remained intact.

Statistical Analysis

Within-group and between-group comparisons were performed for load to failure and cross-sectional area data using one-way analysis of variance and the Tukey honestly significant difference test to perform comparisons between multiple groups. Individual group comparisons were performed using an independent sample, heteroscedastic, two-tailed *t* test. A chi-square test was used to test for significance in mode of failure data. Differences at the $p \leq 0.05$ level were considered significant.

RESULTS

Repair and testing were completed for 38 tendons. Testing was completed for eight tendons in each control cruciate repair group and in the three-strand barbed repair group. Testing was completed for six tendons in the six-strand barbed repair group.

Table 1. Load to Failure of Unbarbed Cruciate Repair versus Barbed Suture Repair*

Repair Group	No. of Tendons in Group	Load to Failure (N)†
Unbarbed cruciate repair		
Monofilament polypropylene	8	29 ± 7
Braided polyester	8	30 ± 8
Fiberwire	8	40 ± 11
All cruciate repairs	24	33 ± 10
Barbed suture repair		
Three-strand	8	36 ± 7
Six-strand	6	88 ± 4

*Cruciate repairs: No significant differences observed between groups. Three-strand barbed vs. unbarbed cruciate, $p = 0.32$; six-strand barbed vs. unbarbed cruciate, $p < 0.001$; three-strand barbed vs. six-strand barbed, $p < 0.001$.

†Values are mean ± SD.

Load to Failure

Load-to-failure data are listed in Table 1. There were no statistically significant differences in mean load to failure between any of the three control groups. Knotless three-strand barbed repair achieved mean load to failure that did not differ significantly from control cruciate repairs, despite having one less core suture. Knotless six-strand repair demonstrated a significantly increased mean load to failure when compared with each of the other groups ($p < 0.001$).

Mode of Failure

The proportion of repairs failing by suture pullout and by suture breakage in each group is shown in Table 2. All tendons in cruciate repair groups failed by knot rupture or suture pullout, whereas the majority of tendons in barbed repair groups failed by suture breakage. This difference in mode of failure was significant ($p < 0.001$).

Repair-Site Distortion

Repair sites are shown in Figure 4, and cross-sectional area data are shown in Table 3. A significant decrease in repair-site bunching (as measured by the ratio of the cross-sectional area of repaired tendon to that of uninjured tendon) was observed between both barbed repair groups and all control cruciate groups ($p < 0.01$). No significant difference was observed between barbed suture groups.

DISCUSSION

The ideal suture for tendon repair should be strong, inelastic, nonreactive, and easy to handle and should knot securely.[10] The ideal suture technique has been described by Momose et al. as easy to perform, strong enough to allow early active motion, and resulting in a smooth external junction without increasing bulk at the repair site.[29] Numerous authors have suggested that the cruciate repair of McLarney et al.[24] and its modifications[18,30,31] approach the characteristics of the ideal tendon suture technique. However, the absolute need for a knot and the reliance on locking suture loops to grip the tendon substance ultimately limit the tensile strength of repairs performed with current suture technology and techniques.

Although the potential benefits of barbed sutures in tendon surgery were recognized as early

Table 2. Mode of Repair Failure*†

Repair Group	Failure Mode Suture Breakage	 Knot Rupture‡	 Pullout
Unbarbed cruciate repair			
Monofilament polypropylene	0/8	5/8	3/8
Braided polyester	0/8	7/8	1/8
Fiberwire	0/8	6/8	2/8
Barbed suture repair			
Three-strand	7/8	N/A	1/8
Six-strand	6/6	N/A	0/6

*Values are number of tendons failing by each mode/total in group.
†Unbarbed cruciate repairs vs. barbed knotless repairs, $p < 0.001$.
‡As there is no knot to rupture in barbed groups, χ^2 analysis was performed by comparing the frequency of suture breakage vs. knot rupture or pullout between barbed and unbarbed groups.

Fig. 4. Repair-site distortion with cruciate technique (*above*) and six-core barbed technique (*center*), in comparison with uninjured tendor (*below*).

Table 3. Cross-Sectional Area Ratio at Repair Site

Repair Group	No. of Tendons in Group	Cross-Sectional Area Ratio†
Unbarbed cruciate repair		
Monofilament polypropylene	8	1.6 ± 0.2
Braided polyester	8	1.3 ± 0.3
Fiberwire	8	1.2 ± 0.2
All cruciate repairs	24	1.5 ± 0.3
Barbed suture repair		
Three-strand	8	1.2 ± 0.2
Six-strand	6	1.2 ± 0.1

*Cruciate repairs: No significant differences observed between groups. Three-strand barbed vs. unbarbed cruciate, $p = 0.009$; six-strand barbed vs. unbarbed cruciate, $p = 0.005$; three-strand barbed vs. six-strand barbed, $p = 0.62$.
†Values are mean ± SD.

as the 1950s by Mansberger et al.[32] and Bunnell,[33] and the application of this concept was first studied by McKenzie in 1967, these early attempts were limited by the materials of the era and never gained widespread popularity.[22] The recent introduction and U.S. Food and Drug Administration approval of barbed nylon, polydioxanone, and polypropylene sutures has reopened investigation into the potential benefits of these sutures in overcoming limitations to flexor tendon repair.

The principal advantage of barbed suture is its unidirectional nature, allowing for smooth, unresisted passage in the direction of the barbs and tissue purchase and firm resistance to passage against the direction of the barbs. This directionality eliminates the need for a knot and therefore eliminates the knot as a potential "weak link" in repair failure. A second theoretical advantage of barbed suture is the more even distribution of load throughout the repair offered by the greater number of points for barb-tendon interaction along the length of the suture. As a result, slippage of locking loops is also eliminated as a potential point of repair failure.

In this study, we found that in our ex vivo model of tendon injury and repair, knotless flexor tendon repair with polypropylene barbed sutures can achieve tensile strength that is equivalent to or stronger than that of unbarbed, locked cruciate repairs. Knotless three-strand repairs provided adequate tensile strength to withstand the forces anticipated during early protected-motion protocols, whereas six-strand repairs exceeded the 40 to 50 N suggested by Amadio et al. as sufficient to initiate early active motion.[34]

In addition, we observed that all unbarbed control repairs failed by knot rupture or suture pullout, whereas 13 of 14 barbed suture repairs failed by suture breakage. We interpret this significant difference in mode of failure to suggest that suture knot strength and inadequate suture tendon interaction were the limiting factors to achieving high tensile strength with the cruciate technique, whereas barbed repairs were limited by the native strength of the suture rather than by slippage. By increasing the suture's diameter or by applying barbs into materials with higher tensile strengths than polypropylene, the potential exists to further increase repair-site tensile strength using this technique.

In addition to maintaining tensile strength, a repaired flexor tendon must be able to pass through the flexor sheath smoothly. Increased bulk caused by fraying, excess suture material, and bunching during repair can inhibit passage through the sheath. Traditionally, this issue has been addressed by the addition of an epitendinous peripheral suture to the strand suture repair, which smooths the repair site, and has been shown to add substantially to the repair strength.[35] In this study, we found that barbed suture repairs resulted in a significantly less bulky repair compared with cruciate repairs. This finding may have implications not only for improving tendon gliding through the sheath but also in limiting or eliminating the need for peripheral tendon suturing.

As the properties of barbed suture in tendon are largely unknown, several significant technical issues warrant further consideration. To maximize the purchase of the barbs of the suture against the tendon fibrils, we designed the repair to traverse the tendon several times perpendicular to the direction of the collagen fibers, creating a "grasping zone" similar to the classic technique described by Bunnell. To minimize the potential for barbed material to sit proud on the gliding surface of the tendon, each time the needle exited the tendon, it was reinserted precisely into the same hole to "bury" the suture loop. Another concern is a potential inability to extract the suture from the tendon if removal were to become necessary. Should intraoperative removal be necessary because of technical error during repair, the suture can be cut at its unbarbed central segment in the tendon injury site, and the needle and suture can be advanced out of the tendon without difficulty.

Another potential concern with this study is the difference in suture diameter and number of strands between control and experimental groups. With regard to suture diameter, inscription of barbs into monofilament suture creates multiple stress risers that decrease its native tensile strength such that a 2-0 barbed suture has tensile strength approximating that of unbarbed 4-0 suture.[25,26] For this reason, 2-0 barbed sutures were selected for use in this study to compare with conventional suture techniques using 4-0 unbarbed sutures. With regard to number of strands, the bidirectional orientation of the barbs and the knotless nature of the repair result in a technique that necessarily produces a repair with three strands crossing the repair site. As it is not possible to produce a symmetric, three-strand cruciate repair with unbarbed sutures, there is a discrepancy in the number of strands used in control groups (four) and in the experimental groups (three or six). Consequently, the results of this study are not intended to demonstrate a difference between repairs using barbed suture and unbarbed suture per se. Rather, the results of this study are intended to compare a technique using barbed suture against a well-studied, widely accepted standard in flexor tendon repair. Additional work would be necessary to determine the safety and efficacy of this technique before its clinical application.

In interpreting the results of this study, we acknowledge several important limitations that should be considered before clinical application of this technique. As repairs were not performed in situ, we cannot assess the ease of this technique in a clinical setting under the constraints of limited exposure, tendon retraction, and tension. However, as the need for grasping or locking loops and knot tying was eliminated, suture placement was technically straightforward and reproducible, and produced consistent results. Because of the ex vivo nature of our study, we cannot assess factors such as tendon ischemia and healing after repair, edema, adhesion formation, tendon gliding, or the mechanical properties of the repair over time. Such information would be necessary before applying this technique in a clinical setting. To address these concerns, this technique could easily be applied to tendon repair in an in situ cadaver model or in vivo animal models such as chicken and rabbit tendons. The biomechanical testing of our repairs used a linear load to failure as the primary outcome, which may not reflect physiologic conditions as well as cyclic loading models. In addition, as our mechanical testing of load to failure included only a qualitative assessment of gap formation, we cannot quantify and adequately compare resistance to gap formation with other techniques. All of these issues present opportunities to further define the potential role for barbed sutures in tendon repair.

CONCLUSIONS

The present study introduces the idea of using barbed suture in flexor tenorrhaphy. In our ex vivo model of flexor tendon repair, a three-strand barbed suture technique achieved tensile strength comparable to that of traditional four-strand cruciate repairs despite having one less core suture, and demonstrated significantly less repair-site bunching. A six-strand barbed suture technique demonstrated markedly increased tensile strength compared with four-strand cruciate controls, and significantly less repair-site bunching. Our data suggest that knotless barbed suture repair may offer several advantages in flexor tenorrhaphy and that further ex vivo and in vivo testing are warranted to evaluate the clinical applicability of this concept.

Pranay M. Parikh, M.D.
Department of Plastic Surgery
Georgetown University Hospital
3800 Reservoir Road
1st Floor PHC Building
Washington, D.C. 20007
pranay.parikh.md@gmail.com

ACKNOWLEDGMENTS

This study was funded by a grant from the Raymond M. Curtis Research Foundation (PMP2007), Curtis National Hand Center, Baltimore, Maryland. The authors thank Sione Fanua, Brent Parks, and Kacey White for technical assistance; Anne Mattson for editorial assistance; and Lorraine Zellers for administrative assistance.

REFERENCES

1. Strickland JW. Flexor tendon surgery: Part I. Primary flexor tendon repair. *J Hand Surg (Br.)* 1989;14:261–272.
2. Strickland JW. Development of flexor tendon surgery: Twenty-five years of progress. *J Hand Surg (Am.)* 2000;25:214–235.
3. Aoki M, Kubota H, Pruitt DL, Manske PR. Biomechanical and histologic characteristics of canine flexor tendon repair using early postoperative mobilization. *J Hand Surg (Am.)* 1997;22:107–114.
4. Cullen KW, Tolhurst P, Lang D, Page RE. Flexor tendon repair in zone 2 followed by controlled active mobilisation. *J Hand Surg (Br.)* 1989;14:392–395.
5. Bainbridge LC, Robertson DC, Gillies D, Elliot D. A comparison of postoperative mobilization of flexor tendon repairs with "passive flexion-active extension" and "controlled active motion" techniques. *J Hand Surg (Br.)* 1994;19:517–521.
6. Silfverskiold KL, May EJ. Flexor tendon repair in zone II with a new suture technique and an early mobilization program combining passive and active flexion. *J Hand Surg (Am.)* 1994;19:53–60.
7. Small JO, Brennen MD, Colville J. Early active mobilisation following flexor tendon repair in zone 2. *J Hand Surg (Br.)* 1989;14:383–391.
8. Sirtotakova M, Elliot D. Early active mobilization of primary repairs of flexor pollicis longus tendon with two Kessler two-strand core sutures and a strengthened circumferential suture. *J Hand Surg (Br.)* 2004;29:531–535.
9. Ketchum LD. Suture materials and suture techniques used in tendon repair. *Hand Clin.* 1985;1:43–53.
10. Trail IA, Powell ES, Noble J. An evaluation of suture materials used in tendon surgery. *J Hand Surg (Br.)* 1989;14:422–427.
11. Viinikainen A, Göransson H, Huovinen K, Kellomäki M, Rokkanen P. A comparative analysis of the biomechanical behaviour of five flexor tendon core sutures. *J Hand Surg (Br.)* 2004;29:536–543.
12. Lawrence TM, Davis TR. A biomechanical analysis of suture materials and their influence on a four-strand flexor tendon repair. *J Hand Surg (Am.)* 2005;30:836–841.
13. Thurman RT, Trumble TE, Hanel DP, Tencer AF, Kiser PK. Two, four, and six strand zone II flexor tendon repairs: An in situ biomechanical comparison using a cadaver model. *J Hand Surg (Am.)* 1998;23:261–265.
14. Barrie KA, Tomak SL, Cholewicki J, Wolfe SW. The role of multiple strands and locking sutures on gap formation of flexor tendon repairs during cyclical loading. *J Hand Surg (Am.)* 2000;25:714–720.
15. Barrie KA, Wolfe SW, Shean C, Shenbagamurthi D, Slade JF III, Panjabi MM. A biomechanical comparison of multistrand flexor tendon repairs using an in situ testing model. *J Hand Surg (Am.)* 2000;25:499–506.
16. Tang JB, Shi D, Gu YQ, Chen JC, Zhou B. Double and multiple looped suture tendon repair. *J Hand Surg (Br.)* 1994;19:699–703.
17. Silva MJ, Hollstein SB, Fayazi AH, Adler P, Gelberman RH, Boyer MI. The effects of multiple-strand suture techniques on the tensile properties of repair of the flexor digitorum profundus tendon to bone. *J Bone Joint Surg (Am.)* 1998;80:1507–1514.
18. Croog A, Goldstein R, Nasser P, Lee SK. Comparative biomechanic performances of locked cruciate four-strand flexor tendon repairs in an ex vivo porcine model. *J Hand Surg (Am.)* 2007;32:225–232.
19. Vinnikainen A, Goransson H, Huovinen K, Kellomaki M, Tormalam P, Rokkanen P. The strength of the 6-strand modified Kessler repair performed with triple-stranded or triple-stranded bound suture in a porcine extensor tendon model: An ex vivo study. *J Hand Surg (Am.)* 2007;32:510–517.
20. Tang JB, Zhang Y, Cao Y, Xie RG. Core suture purchase affects strength of tendon repairs. *J Hand Surg (Am.)* 2005;30:1262–1266.
21. Xie RG, Tang JB. Investigation of locking configurations for tendon repair. *J Hand Surg (Am.)* 2005;30:461–465.
22. McKenzie AR. An experimental multiple barbed suture for the long flexor tendons of the palm and fingers: Preliminary report. *J Bone Joint Surg (Br.)* 1967;49:440–447.
23. Murtha AP, Kaplan AL, Paglia MJ, Mills BB, Feldstein ML, Ruff GL. Evaluation of a novel technique for wound closure using a barbed suture. *Plast Reconstr Surg.* 2006;117:1769–1780.
24. McLarney E, Hoffman H, Wolfe SW. Biomechanical analysis of the cruciate four-strand flexor tendon repair. *J Hand Surg (Am.)* 1999;24:295–301.
25. Villa MT, White LE, Lam M, Yoo SS, Walton RL. Barbed sutures: A review of the literature. *Plast Reconstr Surg.* 2008;121:102e–108e.
26. Rashid RM, Sartori M, White LE, Villa MT, Yoo SS, Alam M. Breaking strength of barbed polypropylene sutures: Rater-blinded, controlled comparison with nonbarbed sutures of various calibers. *Arch Dermatol.* 2007;143:869–872.

27. Tang JB, Wang B, Chen F, Pan CZ, Xie RG. Biomechanical evaluation of flexor tendon repair techniques. *Clin Orthop.* 2001;386:252–259.
28. Wada A, Kubota H, Miyanishi K, Hatanaka H, Miura H, Iwamoto Y. Comparison of postoperative early active mobilization and immobilization in vivo utilising a four-strand flexor tendon repair. *J Hand Surg (Br.)* 2001;26:301–306.
29. Momose T, Amadio PC, Zhao C, Zobitz ME, An KN. The effect of knot location, suture material, and suture size on the gliding resistance of flexor tendons. *J Biomed Mater Res.* 2000; 53:806–811.
30. Barrie KA, Tomak SL, Cholewicki J, Merrell GA. Effect of suture locking and suture caliber on fatigue strength of flexor tendon repairs. *J Hand Surg (Am.)* 2000;26:340– 346.
31. Angeles JG, Heniger H, Mass DP. Comparative biomechanical performances of 4 strand core suture repairs for zone II flexor tendon lacerations. *J Hand Surg (Am.)* 2004;27: 508–517.
32. Mansberger AR, Jennings ER, Smith EP, Yeager GH. A new type pull-out wire for tendon surgery: A preliminary report. *Bull Sch Med Univ Md.* 1951;36:119.
33. Bunnell S. Gig pull-out suture for tendons. *J Bone Joint Surg (Am.)* 1954;36:850–851.
34. Amadio P, An KN, Ejeskar A, et al. IFSSH Flexor Tendon Committee report. *J Hand Surg (Br.)* 2005;30:100–116.
35. Diao E, Hariharan JS, Soejima O, Lotz JC. Effect of peripheral suture depth on strength of tendon repairs. *J Hand Surg (Am.)* 1996;21:234–239.

Online CME Collections

This partial list of titles in the developing archive of CME article collections is available online at www.PRSJournal.com. *These articles are suitable to use as study guides for board certification, to help readers refamiliarize themselves on a particular topic, or to serve as useful reference articles. Articles less than 3 years old can be taken for CME credit.*

Hand/Peripheral Nerve

Effective Surgical Treatment of Cubital Tunnel Syndrome Based on Provocative Clinical Testing without Electrodiagnostics—Daniel P. Greenwald et al.
The Neuromuscular Compartments of the Flexor Carpi Ulnaris—Aymeric Y. T. Lim et al.
Restoration of Elbow Flexion after Brachial Plexus Injury: The Role of Nerve and Muscle Transfers—Karol A. Gutowski and Harry H. Orenstein
Extensor Tendon: Anatomy, Injury, and Reconstruction—W. Bradford Rockwell et al.
Upper Extremity Microsurgery—William C. Pederson
Secondary Carpal Tunnel Surgery—Thomas H. H. Tung and Susan E. Mackinnon
Current Approach to Radial Nerve Paralysis—James B. Lowe, III, et al.
Alternatives to Thumb Replantation—Christoph Heitmann and L. Scott Levin
Management of Secondary Cubital Tunnel Syndrome—James B. Lowe, III, and Susan E. Mackinnon
***Mycobacterium Marinum* Infections of the Upper Extremity**—Christopher L. Hess et al.
Posttraumatic Thumb Reconstruction—Arshad R. Muzaffar et al.
Thumb Trapeziometacarpal Arthritis: Treatment with Ligament Reconstruction Tendon Interposition Arthroplasty—Ashkan Ghavami and Scott N. Oishi
The Surgical Treatment of Brachial Plexus Injuries in Adults—Julia K. Terzis and Vasileios K. Kostopoulos
Treatment of Congenital Upper Extremity Problems—David T. Netscher and Michael A. Baumholtz
Dupuytren's Disease: History, Diagnosis, and Treatment—Robert B. Shaw, Jr., et al.
Management of Wrist Injuries—Kenji Kawamura and Kevin C. Chung
Extensor Tendon Injuries: Acute Management and Secondary Reconstruction—Kevin R. Hanz et al.

Copyright © American Society of Plastic Surgeons. Unauthorized reproduction of this article is prohibited.