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Does Barbed Suture Repair Negate the Benefit of Peripheral Repair in Porcine Flexor Tendon?

Alan Sull[1], Serkan Inceoglu[1], and Montri D. Wongworawat[1]

Abstract

Background: Advances in suture material and geometry have fueled interest in barbed suture tenorrhaphy. Theoretically, barbed suture allows better load distribution, smoother gliding under pulleys, and improved tendon blood flow. Minimal data exist on whether barbed tendon repair may benefit from supplementation by a peripheral stitch. The purpose of this study is to determine whether peripheral suture repair increases gap resistance in both conventional and barbed core repairs, increases maximum tensile strength, and fails before or after the core repair. **Methods:** Porcine flexor tendons were harvested and assigned randomly into 4 groups of 10 of varying suture constructs (3-0 PDS™ or 3-0 V-Loc 180™ core with or without peripheral 5-0 Vicryl™ repair). Core repairs were performed using a modified 4-strand cruciate repair. A servohydrolic tester was used for biomechanical testing of linear 2-mm gap resistance and maximum tensile strength. **Results:** Peripheral repair improved 2-mm gap resistance in all repairs, regardless of core suture type, conventional (173% increase) or barbed (204% increase). No change in the maximum tensile strength was found in either core suture type with peripheral repair. Peripheral repairs always failed before core repairs, at a significantly higher load of 74.2 ± 20.4 N in barbed versus 57.8 ± 12.2 N (P = .04) in conventional core repairs. **Conclusions:** The addition of peripheral repair improved gap resistance but not ultimate tensile strength in both conventional and barbed flexor tendon repairs in linear testing. The 4-strand cruciate flexor tendon repairs using barbed suture may require peripheral repair to withstand physiologic loads, as core repair alone using barbed suture was insufficient.

Keywords: barbed suture, peripheral repair, epitendinous

Introduction

Tendon surgeries have evolved along with postoperative repair-protecting movement programs over decades. Protocols favor early active mobilization over immobilization to minimize adhesions and stiffness,[1] necessitating repairs strong enough to withstand the tensile forces. Studies have measured such digital flexor tendon forces up to 34.32 N[13] during active unresisted finger motion in vivo. Other studies have helped to optimize gap resistance in tenorrhaphy by repairing with a higher strand count,[14] utilizing locked 4-strand cruciate (Adelaide) over nonlocked constructs,[4] 4-mm cross-locks over 2-mm cross-locks,[10] and 10-mm core suture purchase length over 4-mm purchase.[10] Although initially advocated as a cosmetic stitch to improve gliding, peripheral repairs added to core repair have also been found to improve repair strength,[5,17] and it was shown that 6-0 nylon Silfverskiöld peripheral repair increased 3-mm gap resistance by almost 200%.[6]

Barbed suture use in flexor tendon repair was first reported in 1967, using 3-0 nylon suture.[9] Due to poor construction and low tensile strength, however, barbed suture use fell out of favor until recent advances in suture materials and geometry spurred renewed interest.[14] Theoretically, barbed suture tenorrhaphy offers benefits in allowing load distribution along the entire suture length, smoother gliding under pulleys with decreased cross-sectional area under load, and improved tendon blood flow by reduction of constricting forces.[7] Studies have compared barbed suture with conventional nonbarbed suture repair of flexor tendons, with varying suture patterns, loading properties, and tendon models.[11]

Most studies have compared maximum tensile strength and gap resistance of suture types when applied only as core sutures,[8] and it is largely unknown whether barbed tendon

[1]Loma Linda University, CA, USA

Corresponding Author:
Montri D. Wongworawat, Department of Orthopaedic Surgery, Loma Linda University, 11406 Loma Linda Drive, Suite 218, Loma Linda, CA 92354, USA.
Email: dwongworawat@llu.edu

repair would benefit from supplementation by a peripheral running stitch. Only one study to date has reported tensile strength of barbed suture repair in flexor tendons with additional peripheral repair,[16] but findings were limited by an unconventional model apposing different flexor tendon zones and resulting in substantially higher failure loads than previously published.

The purpose of our study is to study the differences between conventional and barbed suture core repairs and determine whether (1) additional peripheral suture increases gap resistance, (2) peripheral repair increases ultimate tensile strength, and (3) differences exist in failure sequence.

Methods

Forty porcine flexor digitorum profundus tendons were harvested and separated randomly into 4 groups. The deep flexor tendons were harvested from the 2 central rays of each forelimb and transected 5 mm proximal to the long vinculum, within the Zone II region as described in prior ex vivo tendon repair studies.[10] All tendons were of comparable size and shape with no gross abnormalities on visual inspection. The 4 suture material/technique test groups consisted of the following:

- Group 1—absorbable monofilament polydioxane suture (PDS™ 3-0, Johnson & Johnson, Somerville, New Jersey);
- Group 2—absorbable unidirectional barbed glycolic-carbonate suture (V-Loc 180™ 3-0, Covidien, Dublin, Ireland);
- Group 3—equivalent to group 1 with an additional peripheral running braided polyglactin suture (Vicryl™ 5-0, Johnson & Johnson);
- Group 4—same as group 2 with an additional peripheral running braided polyglactin suture (Vicryl™ 5-0, Johnson & Johnson).

Adelaide type core repair was conducted using the monofilament suture with 4-mm cross-locks and 1-cm suture purchase with a buried 6-throw square knot, and a knotless, modified Adelaide repair was performed using the barbed suture, terminating in reverse throw.[7] Peripheral suture repairs were performed using a running, nonlocked suture with a buried knot and 2-mm suture purchase with 2-mm depth. All repairs were performed by a single surgeon (A.S.). Absorbable sutures were used for core and peripheral repairs, as they have been used in prior studies.[4,7,12,17,18]

Repaired tendons were mounted into serrated soft tissue clamps, with the bottom clamp attached to an immobile platform and top clamp attached to a mobile actuator. Tendons were mounted into the clamps at 2.0-cm distance from the repair site. Tendons were preloaded to 3 N and then stretched linearly by the Instron™ machine (model 8521, InstronCorp, Canton, Massachusetts) at a rate of 20 mm/min until failure. Each trial was recorded using a digital video camera and a ruler was positioned next to the tendon to provide a reference of length.

To look for differences in gap resistance, frame-by-frame analysis was conducted. We recorded the load at which a 2-mm gap distance was measured at the midpoint of tendon ends. Kruskal-Wallis 1-way analysis of variance (ANOVA) with Tukey tests was used to evaluate significance for 2-mm gap resistance with significance set at $P < .05$.

To evaluate maximum tensile strength, we first defined the time point as failure of core repair, as in all samples the peripheral repair failed first. The load at which core suture repair failed was recorded and 1-way ANOVA used to compare group means.

To examine whether peripheral repair had a differential effect on core suture types, we recorded the load at which peripheral repair failed in groups 3 (PDS™ core) and 4 (V-Loc™ core). Student 2-tailed t test was then used to compare the means with significance set at $P < .05$.

Results

Two-millimeter Gap Resistance

The addition of peripheral repair improved gap resistance, regardless of core suture type. The loads at 2 mm measured gap formation were 22.6 ± 3.8 N and 25.1 ± 4.0 N for groups 1 and 2, respectively, and 61.7 ± 5.0 N and 76.4 ± 21.1 N for groups 3 and 4, respectively (Figure 1). The addition of peripheral 5-0 Vicryl™ repair (group 3) increased 2-mm gap resistance by 173% over PDS™ core repair alone (group 1); this change represented a significant increase ($P < .05$). The addition of peripheral repair (group 4) increased gap resistance by 204% over V-Loc™ core repair alone (group 2); this change represented a significant increase ($P < .05$). No difference was found between core suture types (groups 1 vs 2 or groups 3 vs 4, respectively).

Core Tensile Strength

Peripheral repair did not cause a statistically significant change in the maximum tensile strength of core repairs. The maximum tensile strength, reported as failure of core suture, was 83.3 ± 10.0 N, 76.0 ± 9.4 N, 87.6 ± 8.8 N, and 87.1 ± 12.0 N for groups 1, 2, 3, and 4, respectively (Figure 2); no differences between these groups were found ($P > .05$). There was one case of core suture pullout in each group; all the rest failed by suture rupture. No cases of knot unraveling were seen.

Peripheral Tensile Strength

The peripheral repair always failed prior to the core suture repair. Peripheral suture tensile strengths were 57.8 ± 12.2 N

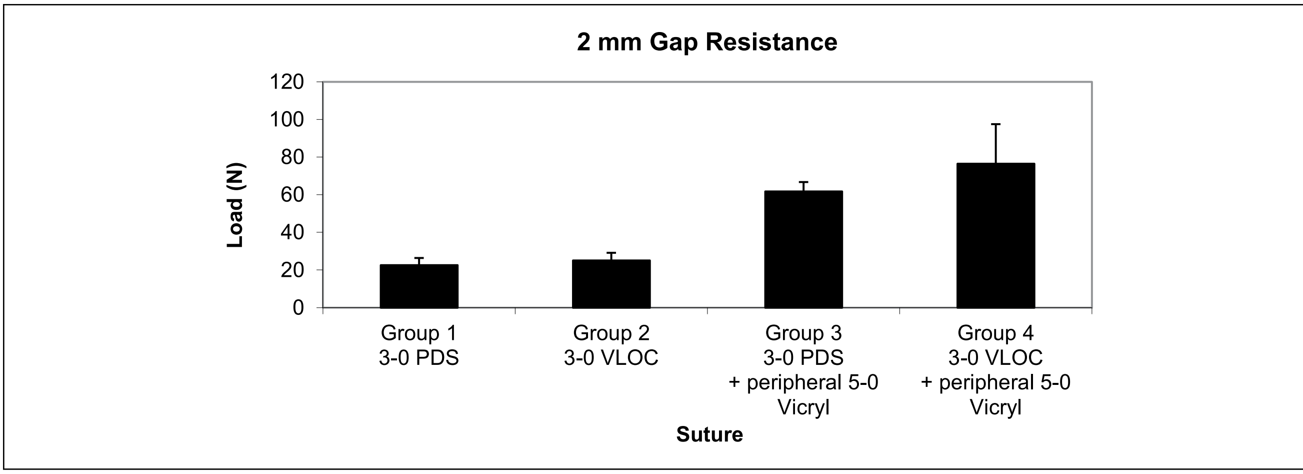

Figure 1. Conventional PDS™ and barbed V-Loc™ repairs produced similar 2-mm gap resistance, and the addition of peripheral 5-0 Vicryl repair increased gap resistance by 173% and 204%, respectively.

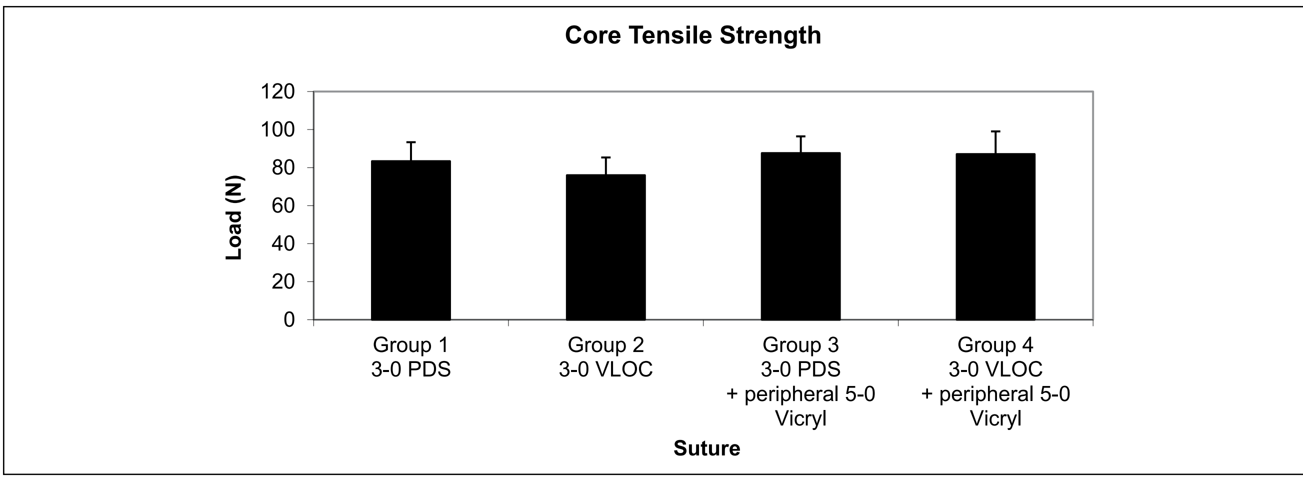

Figure 2. Maximum strength of core repair was similar across all groups regardless of suture type, and peripheral repair did not cause a statistically significant change in the maximum tensile strength of core repairs.

and 74.2 ± 20.4 N, respectively, for PDS™ core with peripheral repair (group 3) and V-Loc™ core with peripheral repair (group 4; Figure 3), which were found to be statistically significant (P = .04). All peripheral repairs failed by suture rupture except one case of suture pullout in group 3.

Discussion

Many different flexor tendon repair techniques have been described, using barbed and conventional suture materials and repair geometries, but no consensus exists regarding the best method. Although circumferential repair was shown to augment conventional core repair, the effect on barbed core repair was largely unknown. Therefore, we aimed to determine whether peripheral repair would augment the strength of barbed core repair in similar fashion.

We found that 2-mm gap resistance improved with peripheral repair in both barbed and conventional core repairs. Other studies have demonstrated similar findings.[10] Furthermore, we found comparable 2-mm gap resistance in barbed versus similarly rated conventional sutures, which also corroborates with prior studies,[9] although the range of tensile strengths in other studies is vast due to the use of different sutures materials and ex vivo models.[2,3,15,19] In linear testing, the 2-mm gap resistance likely translates to a more clinically applicable figure than maximum tensile strength. In our samples, it appeared that maximum tensile strength of core sutures was reached after gapping over 10 mm, but prior studies have shown that 2-mm or larger gap formation during repaired flexor tendon mobilization significantly increases catching at the pulleys and gliding resistance.[19] Therefore,

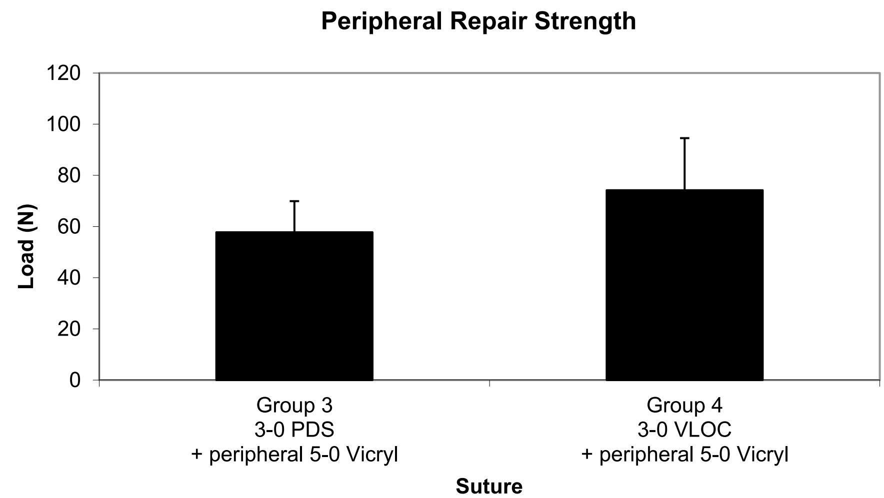

Figure 3. The peripheral repair in group 4 failed at a higher load than the peripheral repair in group 3.

the ultimate tensile strength of the core sutures was reached long after the repair integrity was lost.

Although gap resistance increased by adding a peripheral repair, maximum tensile strength of the core repair remained unaffected. This is likely due to the fact that once the peripheral repair failed, the load transferred to the core repair, resulting in equivalent tensile strength measurements for the core sutures at failure in all groups. As noted in prior studies, the core tensile strength in this setting seems to offer less clinically relevant information than gap resistance, as the core sutures grossly tended to rupture or pull out when the gap distance was over 10 mm.

We found that circumferential repair has a greater synergistic effect with barbed core repairs than conventional suture repairs, demonstrated by the measured difference between peripheral repair strengths of groups 3 and 4. Although further studies are needed to elucidate the reason for this, the increased synergism may be due to better load distribution of the barbed suture throughout its length.

Several limitations in our study must be acknowledged. First, our testing protocol only considered initial mechanical performance of the constructs. However, the response of these constructs to long-term cyclic loading should also be studied, as they may better mimic physiologic loads to failure. Another limitation is that conventional versus barbed repair geometries, although similar, were not completely identical. We opted for the modified Adelaide repair terminating in a reverse stitch because of its similarity to the Adelaide repair while in accordance with manufacturer recommendations. Third, it is unclear how strong the peripheral repair alone is. Increased gap resistance by 200% suggests that either the peripheral repair adds a synergistic effect to the core repair or the peripheral repair alone may offer higher gap resistance than the core repair alone. Other important variables that may affect tendon repairs that were excluded by study design include the effect of knotless versus conventional repair in tendon healing, as well as the absorption profiles of suture materials. In vivo use of barbed sutures may be enhanced as we continue to optimize each variable.

In conclusion, peripheral suture repair enhances gap resistance in both conventional and barbed core suture repairs, and there may be a greater synergistic effect of peripheral repair with barbed over conventional core repairs. Barbed suture core repairs present a viable alternative to conventional repairs, although further studies are needed to clarify cyclic tensile strengths in vivo along with optimizing repair geometries and suture materials.

Authors' Note

This article was recently selected as an oral presentation at the 2015 American Association for Hand Surgery Annual Meeting.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

Informed consent was obtained when necessary.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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