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Hand/Peripheral Nerve

A Barbed Suture Repair For Flexor Tendons: A Novel Technique With No Exposed Barbs

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Background: Barbed suture technology has shown promise in flexor tendon repairs, as there is an even distribution of load and the need for a knot is eliminated. We propose that a quick and simple, novel, barbed technique without any exposed barbs on the tendon surface has comparable strength and a smaller cross-sectional area at the repair site than traditional methods of repair.

Methods: Forty porcine flexor tendons were randomized to polybutester 4-strand barbed repair or to 4-strand Adelaide monofilament repair. The cross-sectional area was measured before and after repair. Biomechanical testing was carried out and 2-mm gap formation force, ultimate strength of repair, and method of failure were recorded.

Results: The mean ultimate strength of the barbed repairs was 54.51 ± 17.9 while that of the Adelaide repairs was 53.17 ± 16.35. The mean 2-mm gap formation force for the barbed group was 44.71 ± 17.86 whereas that of the Adelaide group was 20.25 ± 4.99. The postrepair percentage change in cross-sectional area at the repair site for the Adelaide group and barbed group was 12.0 ± 2.3 and 4.6 ± 2.8, respectively.

Conclusions: We demonstrated that a 4-strand knotless, barbed method attained comparable strength to that of the traditional Adelaide repair technique. The barbed method had a significantly reduced cross-sectional area at the repair site compared with the Adelaide group. The 2-mm gap formation force was less in the barbed group than the Adelaide group. Barbed repairs show promise for tendon repairs; this simple method warrants further study in an animal model. *(Plast Reconstr Surg Glob Open 2014;2:e237; doi: 10.1097/GOX.0000000000000203; Published online 23 October 2014.)*

Flexor tendon repair methods have evolved over the years, and multistrand core suture techniques have become the gold standard repair technique. However, there is no widespread agreement over the ideal number of strands or suture material used.[1,2] Four-strand cruciate repair methods have grown in popularity and provide a compromise between complexity and strength.[3]

Despite refinements in repair methods and reduced rates of rupture, there are several drawbacks to traditional repair methods. The presence of a knot has been shown to be a weak point in the repair,[4–7] and it also increases the cross-sectional area (CSA) at repair site, thereby adversely affecting gliding through the intricate pulley system.[5,8] There is a theoretical disadvantage if locking configurations are used for repair, as they can act in a constricting

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manner that may have a negative impact on the vascularity and healing capabilities of the tendon.[3,9,10]

The advent of barbed suture technology could conceivably avoid some of the limitations of traditional repair methods. The potential advantage to barbed sutures for tendon repairs is that the load is distributed evenly throughout the intratendinous suture length rather than creating stress points at the locking zones. Furthermore, this even distribution of load would reduce the constricting action of the suture on the tendon.[3]

The use of a barbed device for tendon repair was first described by McKenzie[11] in 1967, but there has been little reported on their use until quite recently. There are now several commercially available barbed suture devices on the market, but they are not licensed for tendon repairs as of yet. Their main use has been in wound closure[12,13] and abdominal[14] and gynecological procedures.[15]

Barbed suture devices have been described before for flexor tendon repairs,[3,6,11,16–20] and the results have been promising. A major advantage in using barbed sutures is that there is no requirement for a knot. This creates a reduced CSA at the repair site and also permits a quicker repair.[17] A major concern with most barbed repair techniques described to date has been the presence of barbs on the outer surface of the tendon. These have the potential ability to cause attritional damage to the pulley system in vivo, which increases gliding resistance and promotes adhesion formation.[3]

We have compared a simple and quick barbed suture repair without any exposed barbs on the tendon surface to a traditional 4-stranded Adelaide repair using a monofilament suture.[21]

MATERIALS AND METHODS

We used 40 fresh porcine flexor digitorum profundus tendons for our study. Porcine tendons are routinely used in flexor tendon studies, and they best represent the zone II flexor digitorum profundus tendon of the human middle finger in terms of biomechanical properties.[17,22–27] All tendons were examined carefully and any found with defects or abnormalities were discarded.

CSA Measurements

We aimed to ensure that all tendons were relatively uniform. A digital caliper (Digi-Max slide caliper, Bel-Art, N.J.) was used to measure the width and height of each individual tendon. As in our previous described method,[17] we measured each tendon at the repair site and 1 cm proximal and distal to this. The formula for calculating an ellipse (CSA = πab, where a equals half of the long axis of the tendon cross-section and b equals half of the short axis of the tendon cross-section) was used to calculate the CSA at each point before and after the tendon repair.

Repair

The fresh tendons were randomly allocated to either the barbed suture arm of the study or the Adelaide repair arm. A 15 blade scalpel was used to transect each tendon at the previously marked site and repaired immediately according to the group assigned. Each knot in the Adelaide received 6 throws to ensure uniformity and prevent unraveling.[4,19,28]

Under 3.5× loupe magnification, all repairs were carried out by a hand surgeon (C.W.J.). A core suture purchase of 10 mm was used on all flexor tendon repairs and cross-locks were 4 mm wide[29] in the Adelaide group (Fig. 1). The traditional 4-strand Adelaide repair was performed using a nonabsorbable monofilament polypropylene suture (Prolene; Ethicon, Somerville, N.J.). As previously described,[17] the diameter of this suture material ranged from 0.200 to 0.249 mm. The barbed knotless repair technique was carried out using a nonabsorbable polymer 2-0 barbed V-Loc polybutester (Covidien, Mansfield, Mass.) (Fig. 2). The diameter of the barbed device ranged from 0.300 to 0.339 mm. Barbed sutures are rated as equal to one United States Pharmacopoeia suture size larger than their standard equivalent. This is because there is a loss of the effective diameter during the process of creating the barbs.[30] We compared a 2-0 barbed suture with a 3-0 polypropylene suture as their tensile strengths have been shown to be very similar.[31,32] An epitendinous tendon repair was not carried out in either group in our study, as we were only interested in examining the core strength of each repair method.

As described before, the 2-0 V-Loc device is a single-ended unidirectional barbed suture with a welded loop at the end. There are 26 barbs per centimeter of material, and they are distributed circumferentially around the suture at 120° rotations with each barb 0.38 mm in length. Our barbed repair technique used 4 strands. The welded loop was not required for our repair method and so was cut off from the suture. The needle was passed through the tendon surface on one side, across the repair site and then out through the surface on the other side. Each pass was made through the midsubstance of the tendon, and they were made 2 mm apart from one another.

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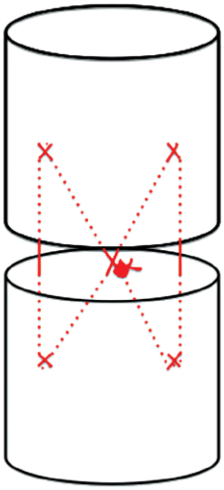

Fig. 1. The 4-strand Adelaide repair.

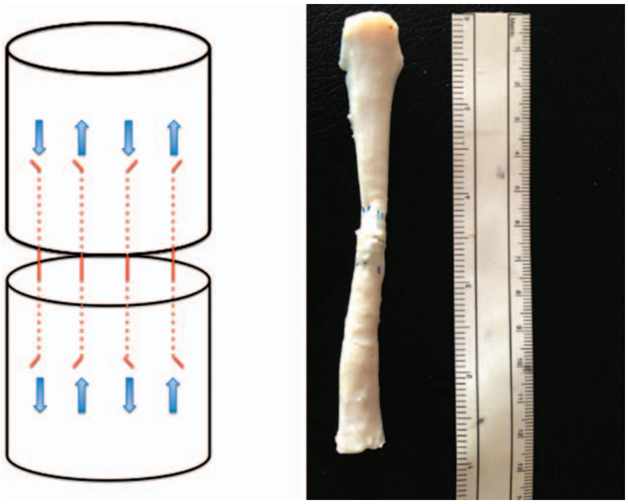

Fig. 2. Diagram and photograph of the 4-strand knotless barbed repair. The blue arrows represent the direction the barbed suture passed through the tendon.

This was repeated 4 times for each repair and the suture was cut flush to the tendon surface each time, so no barbs were present on the exposed tendon. To facilitate a solid, nonslip repair, each barbed suture strand was placed in an opposing direction to the one beside it. A core suture purchase of 10 mm was made for the barbed technique as well.

Biomechanical Testing

Repaired tendons were mechanically tested with a Zwick Z005 tensiometer (Zwick Z005, Ulm, Germany). To simulate the forces that act on an immobilized tendon during active flexion, the upper clamp of our material testing machine was set with a preload of 1.5N and an advancement rate of 20 mm per minute.[33,34] These settings have been used previously in biomechanical tests on flexor tendons.[19] The repaired tendons were secured tightly in the upper and lower sandpaper covered clamps before mechanical testing. There was no slippage of the tendon ends during testing.

A caliper with a preset of 2 mm was set up alongside the tensiometer. When a 2-mm gap at the repair site occurred during testing as measured by the caliper, the corresponding force that created this gap was recorded. The ultimate failure load of each repair was also recorded. This is the greatest force that occurs immediately before tendon repair failure. The mode of final failure (rupture or pullout) was also recorded.

Statistical Analysis

A power analysis was carried out to determine the sample size in each arm of our study. This was based on maximum strength/ultimate force, and the study was powered to detect a 10N difference in maximum force. We performed a pilot study and results from this indicated that we required a minimum of 15 porcine tendons in each group for 0.80 power in the study to detect a significant difference of $P < 0.05$. Kolgomorov-Smirnov method was performed to determine the normality or otherwise of the data distribution. The 2-mm gap formation force and the maximum force were compared using Student's *t* test with Welch correction. The difference in CSA between the 2 groups was compared using the Mann-Whitney test. Before analysis was carried out, log transformations of the maximum force, 2-mm gap formation force, and percentage change in CSA were performed. A P value of <0.05 was considered to be statistically significant.

RESULTS

Maximum Force

The cause of repair failure for the barbed group was rupture in 12 cases and pullout in the remainder of the samples tested. For the Adelaide repair, there were 8 ruptures and 12 pullouts. Seven of the ruptures in the Adelaide group occurred at the knot. A repair failure was classified as a pullout if the suture strands pulled through the tendon without breaking. Rupture occurred when either the strands or knot broke. The maximum or ultimate force before repair failure can be seen in Table 1. There was no statistically significant difference between the 2 groups of tendon repairs (*t* test, $P > 0.05$).

2-mm Gap Formation

The formation of a 2-mm gap at the repair site is widely regarded as a failed repair, and the force that caused a 2-mm gap at the repair site was measured in the 2 groups (Table 1). The results were extremely statistically significant (*t* test, $P > 0.0001$).

Table 1. Data from the Tensile Testing of the Sutures and Cross-sectional Area Measurements

Repair Method	Maximum Force, *N*	2-mm Gap Force, *N*	CSA, mm^2	Change in CSA, %
Barbed	54.5 (17.9)	44.71 (17.8)	23.7 (3.16)	4.6 (2.8)
Adelaide	53.1 (16.35)	20.2 (4.99)	24.0 (2.7)	12.0 (2.3)

Values are mean (SD).

Change in CSAs

The change in the CSAs at the repair site pre- and postrepair are seen in Table 1. No significant difference was observed in the 2 groups in the prerepair CSA. However, postrepair, there was a statistically significant difference in the CSAs (Mann-Whitney test, $P < 0.0003$).

DISCUSSION

Trail et al[2] reported that the ideal material for flexor tendon repair should be strong, inelastic, easy to handle, and create a strong, robust knot. Several authors have reported that the cruciate multistrand repair method and its variations most closely meet the criteria for the ideal tendon suture technique.[35,36] These flexor tendon repair methods were specifically designed with conventional suture materials in mind. These techniques are reliant on a knot and holding or locking zones to grip the tendon. These locking configurations can cause excess bunching, thus adding to the CSA at the repair site, which impairs tendon gliding through the pulley system.[6]

Barbed suture technology has advanced significantly since McKenzie[11] first detailed the use of barbed steel wire in flexor tendon repairs. The renewed interest has only been quite recent, yet to date, there are 3 types of barbed sutures commercially available: V-Loc (Covidien), the Quill device (Angiotech, Vancouver, BC, Canada), and Stratafix (Ethicon). The latter two are bidirectional devices with a needle on either end of the suture, and the midpoint of the device is where the barbs change direction. The V-Loc is unidirectional with a welded loop at one end. The advantages of barbed sutures include the smooth passage in the direction of the barbs with a strong resistance to passage against the direction of the barbs.[6] This unique design eliminates the requirement of a knot and therefore removes a significant weak point of the repair.[19] Also, the intimate barb-tendon interaction throughout the repair provides a more even distribution of load and eliminates the need for locking loops. As a consequence, the slippage of these locking loops is eliminated as a source of repair failure.[6]

Several studies have looked at the use of barbed devices in tendon repairs,[3,6,11,16–20] yet many of the techniques have been quite complex and laborious. The noted advantages of barbed sutures for wound closure have been the lack of knot and the ease and speed of closure. Until now, no previous flexor tendon repairs using barbed devices have been simple and quick.

We have described a novel technique for flexor tendon repairs using a barbed suture device in which the directionality of the barbed suture is used to hold the repair. We found our barbed repair much easier and faster to perform and required fewer hand movements than the Adelaide repair. The barbed device was easier to handle than the polypropylene as we found that the barbs act as a grip. We also noticed that if technical errors were made during the barbed repair method, they were easy to rectify by pulling the suture out in the direction of the barbs. This is in contrast to more complex barbed suture repairs that have been described, where technical errors are not as easy to correct, as multiple suture passages of the suture within the tendon substance make it more difficult to extract the suture.[6]

We did not observe any significant difference in the tensile strengths of both repair methods as both repair methods failed at comparable forces. Gap formation is a common complication post flexor tendon repair that can adversely affect the end result and prolong tendon healing.[37] There was a statistically significant difference in the 2-mm gap formation force required in the 2 groups. The barbed repair method was able to withstand more force than the traditional repair method before a 2-mm gap formed at the repair site. We did not pretension either material before repair so this may have had an effect on the gapping forces for the Adelaide group.[38]

Repaired flexor tendons should be able to pass freely through the flexor sheath. Repairs typically add bulk to the repair site due to bunching of the tendon ends and the presence of the knot and suture material. This increased CSA can impair tendon gliding and overall outcome.[17] In our study, we found that the barbed suture group had a significantly reduced CSA than the Adelaide group. This would allow smoother gliding through the pulley system and could reduce the postoperative rupture rate.

A limitation of our study is that we used a caliper preset to 2 mm to calculate the 2-mm gap formation force. As distraction occurred at a rate of

20 mm/min, it was difficult to accurately assess the 2-mm gap formation force by visual estimation.

It would have been preferable to carry out our experiments using identical suture materials, as we directly compared a polybutester barbed suture to a polypropylene monofilament suture. Our biomechanical testing used a linear load to failure as one of the primary outcomes. To better replicate physiological conditions, it would have been interesting if angular tensile strengths or cyclical loading studies had been carried out.

CONCLUSIONS

The knotless barbed repair method we have described is a quick and easy technique that provides a strong repair without significantly increasing the bulk of the repair site. Our novel 4-strand knotless barbed technique had comparable tensile strength with a reduced CSA at the repair site in relation to the traditional 4-strand Adelaide repair. Furthermore, our barbed technique has no exposed barbs on the tendon surface, so there should be no attritional damage to the pulley system in vivo. The use of barbed devices for flexor tendon repairs shows promise, but further studies using animal models are warranted to examine their clinical applicability.

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