Barbed Suture in Tendon Repair

Abhishek Vijayakumar*, Pavan Murdeshwar and Hemang Sanghvi

The Bangalore Medical College and Research Institute, Krishna Rajendra Road, Fort, Kalasipalyam, Bengaluru, Karnataka 560002, India

Abstract: Hand tendon lacerations are difficult to treat with over 25% of patients achieving an unsatisfactory clinical outcome as assessed by the clinician, and 7.7% of repairs re-rupture, requiring further surgery. The suture materials, which are available today possess tensile strengths capable of withstanding forces far above what occurs during active treatment. The current suture techniques have some disadvantages of bulky repair, adhesion formation and delayed tendon rupture. With availability of better designs of Barbed sutures like Quill™, Vloc™ and Stratafix™ it has opened up a scope for new research into tendon repair. Various *ex vivo* studies have shown that a four strand repair using barbed suture has similar strength to conventional repair and adding an epitendinous suture adds on to repair strength. The Barbed suture repair reduces the cross sectional area at repair site, which may translate to reduced gliding resistance. There is need for clinical studies to analyze the effectiveness of Barbed suture in tendon repair in clinical setting and explore the potential advantages. Level of evidence II

Keywords: Barbed suture, Vloc, Quill, Stratafix, Tendon repair, Gliding resistance, Breaking strength.

1. INTRODUCTION

Hand tendon lacerations are difficult to treat with over 25% of patients achieving an unsatisfactory clinical outcome, and 7.7% of repairs re-rupture, requiring further surgery [1].

Achieving sufficient repair tensile strength to allow for early passive and active motion is important for functional rehabilitation and favorable outcomes following flexor tendon injury and repair [2,3]. For functional after-care to be safe tendon repair strength has to be between 9 N for the passive mobilization, and 35 N for active mobilization for the finger [4]. Tendon repair strength depends on biomechanics of tendon sutures particularly the material and technique used [5,6]

2. DISADVANTAGES OF CURRENT TENDON REPAIR TECHNIQUES

The suture materials, which are available at present possess tensile strengths capable of withstanding forces far more than what occurs during active treatment. Due this reason, suture ruptures are rarely the cause of suture insufficiency [7,8].

Although an increase in the number of suture strands and additional circumferential sutures increases the immediate tensile strength of repair [9]. Considerable interactions between tendon and suture material and especially at the locking configuration is seen, which may finally influence the overall tensile strength of tendon [10,11].

Knots are potential weak points in tendon suturing and tend to give up during increasing tension [12]. The strength of a given repair is depends on how effectively it transmits axial tension into grip onto the tendon fibre bundles. Barbed suture theoretically may increase the transmission of axial load transversely onto tendon fibres thus allowing lesser suture material in core strands of the repair and reducing bulky repairs.

Maintaining glide between the tendon and sheath is of great importance when considering an ideal tendon repair. The force required for movement is greater in a repaired tendon due to edema, damage to the gliding surfaces, and presence of the repair itself [13]. The increased numbers of core suture add to bulk of repair also externally placed anchoring points and knots decrease gliding of tendons [14]. An excess of external suture increases gliding resistance, as demonstrated by Angeles *et al*. [15] who evaluated the relative advantages of six different suturing techniques using cadaver hands. Suture knot location also affects glide. The Tajima repair where the knot is internal, exhibits significantly lower gliding resistance than Kessler, which is identical except for an externally placed knot [16]. Knot placement between the cuts should be avoided as this reduces the tendon end contact surface area that is involved in healing [17]. Another important factor in tendon repair outcome is prevent formation of adhesions. Bunnell's philosophy of minimal handling, and care to avoid vascular interference must also be observed. Paradoxically this means current multistrand repair techniques, which are stronger and gap resistant,

*Address correspondence to this author at #128 Vijay Doctors Colony Konanakunte Bangalore 560062, India; Tel: 9980579089; E-mail: email:abhishekbmc@yahoo.co.in

are reduce glide and cause increased tissue trauma. The barbed sutures can reduce the number of core strands and external passes thus reducing trauma and adhesion formation.

It has been shown that the process of suturing tendon causes cell death directly [17]. In an animal model it has revealed the formation of an acellular zone around suture within 72 hours and persists for upto 1 year. This acellular zone forms as a result of tension placed across suture grasp. The effect is lessened without this tension. Wong *et al*. [18] reported acellular regions within the tendon when internal suture is present under tension. Healing was not observed in acellular zones, and prolonged inflammation occurred at the sites of suture, which potentially stimulated adhesion formation. The clinical relevance of these findings is cell death, inflammation and extracellular matrix breakdown are occur most at the areas of highest stress in repairs, mainly around the locking and grasping throws, which could potentially explain the pathophysiology of many cases of rupture and adhesion formation. Barbed suture may eliminate high stress zones by evenly distributing the pressure over vast area of barbs and also delayed absorbable suture may negate the long-term effect of permanent sutures. Further works are needed to demonstrate this effect.

Thus even with modern suture material and advanced suturing techniques of tendon repair there are still issues like knot failure, bulky repair, adhesion formation and tendon ruptures. There is a scope for barbed sutures, which could solve some of these problems.

3. BARBED SUTURE IN TENDON REPAIR

In the 1950s, barbed sutures was described by Bunnell for tendon repairs [19]. However, it wasn't until 1967 that a biomechanical comparative study was first done by McKenzie. He compared tendon sutures with multiple barbed sutures with stainless steel, silk and nylon sutures [20]. The original report demonstrated that repair with custom-fabricated, barbed 3-0 nylon suture could achieve tensile strength of 17.8 to 26.7 N, equivalent to that of two-strand Bunnell repair with G40 stainless steel wire. Early reports were not very promising and further testing abandoned. Many of the technical comments mentioned in these articles were state of the art in tendon surgery in that era but no longer apply to present practice [21].

The recent introduction and U.S. Food and Drug Administration approval of barbed nylon, polydioxanone, and polypropylene sutures has revised investigation into the potential benefits of these sutures in overcoming limitations to flexor tendon repair.

Ingle *et al*. [22] in a finite element model, studied different configurations of barbs and the mechanical interaction with surrounding skin and tendon tissue with the goal of optimize suture function. He concluded that since the tendon tissue has a higher modulus than the skin, it needs a more rigid barb to penetrate and anchor the surrounding tissue. A cut angle of 150° and a cut depth of 0.18 mm were therefore recommended. On the other hand, for the softer skin tissue, a cut angle of 170° and a cut depth of 0.18 mm provide a more flexible barb that gives superior skin tissue anchoring [22,23].

With availability of better designs of Barbed sutures like Quill™, Vloc™ and Stratafix™ it has opened up a scope for new research into tendon repair. Various *ex vivo* studies have been undertaken to study the repair technique and effectiveness of barbed suture (Table **1**).

The studies have shown that a four-strand repair using barbed suture has similar strength to conventional repair and adding an epitendinous suture adds on to repair strength. The Barbed suture repair reduces the cross sectional area at repair site, which may translate to reduced gliding resistance. Because of the *ex vivo* nature of studies, 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. There is need for clinical studies to analyze the effectiveness of Barbed suture in tendon repair in clinical setting and explore the potential advantages.

4. CONCLUSION

The concept of Barbed sutures in tendon repair have re emerged as a result of advances in suture technology. Barbed suture may eliminate some problems faced with conventional tendon repair like bulky repair, adhesion formation, tendon rupture. The current *ex vivo* studies demonstrate similar strength of barbed suture and conventional suture in tendon repair. There is need for clinical studies to analyze the effectiveness of Barbed suture in tendon repair in clinical setting and explore the potential advantages.

Table 1: Studies of Barbed Suture in Tendon Repair

Name	Methods	Result /Conclusion
Parikh *et al*. 2009 [24]	Cadaveric flexor tendon 3 and 6 strand core suture repair with bidirectional barbed suture vs 4 strand core suture unbarbed suture. Linear loading strength and cross section area analyzed.	A 3-strand barbed suture technique achieved tensile strength comparable to that of 4-strand cruciate repairs and demonstrated significantly less repair-site bunching. A 6-strand barbed suture technique demonstrated increased tensile strength compared with 4-strand cruciate controls and significantly less repair-site bunching.
Trocchia *et al*. 2009 [25]	Cadaveric flexor tendon 2 strand Kessler repair with Ethibond 3-0 vs 2 strand Kessler Bunnell repair with 2-0 polypropylene Quill™ linear loading strength.	Tensile load at 2-mm gapping was 22.8±6.3 N and 22.2±4.0 N for Ethibond and Quill, respectively. No statistical significance was found (P=.723). Equal strength between barbed and unbarbed repair.
McClellan *et al*. 2011 [26]	Porcine flexor tendon 2 strand Kessler 4 strand Savage repair vs 4 strand barbed suture repair. Tensile strength and cross section area analyzed.	Strength of the Savage and knotless technique groups were not significantly different; however, both were significantly greater than those of the Kessler repair group ($p < 0.05$). Knotless flexor tendon repair with barbed suture has equivalent strength and reduced repair-site cross-sectional area compared with traditional techniques.
Zeplin *et al*. 2011 [27]	Cadaveric flexor tendon 2 and 4 strand Glycolic carbonate knotless barbed repair vs 2 and 4 stranded Polydioxane knotted repair. Linear loading Tensile strength analyzed.	The knotless 2-strand barbed suture shows a significantly lower tensile strength than the knotted 2-strand polydioxane suture ($p < .001$). The comparison of the maximum tensile strength of the knotless (glycolic-carbonate) technique with that of the knotted (polydioxane) 4-strand technique resulted in no significant difference in either technique utilized ($p = .737$). The tensile strength of the 4-strand technique was greater than that of the corresponding 2-strand technique ($p < .001$).
Marrero *et al*. 2011 [28]	Cadaveric flexor tendon 4 strand core repair with Ethibond with additional epitendinous suture. Vs 4 strand core repair with barbed suture. Linear loading to failure analyzed.	The average maximal load to failure was not significantly different between the traditional repair (48 ± 12 N) and the barbed suture repair (50 ± 14 N). Barbed suture repair equal strength to traditional repair.
Zeplin *et al*. 2012 [29]	Cadavric flexor tendon 4-strand Kirchmayr-Kessler suture technique separated into four groups. Group 1 - polydioxane; Group 2 - barbed suture; Group 3 and 4 - same as group 1 and 2 with an additional peripheral running suture. Tensile strength for linear and cyclical loads analyzed	No difference in maximum tensile strength after linear and cyclical force could be detected between the knotted polydioxane suture and the knotless barbed suture. Linear force tests an additional circumferential repair increased the maximum tensile strength of both sutures.
Lin *et al*. 2013 [30]	Cadaveric flexor tendon repair with 4 strand Kirchmayr- Kessler with 3-0 braided Polyester vs knotless 4 strand Kirchmayr- Kessler with 0 unidirectional barbed suture. Linear loading tensile strength compared.	The mean maximum load of the barbed, knotless suture repair was higher than that of the traditional repair (52 vs. 42 N). The four-strand knotless tendon repairs using a large-diameter unidirectional barbed suture are stronger than the traditional four-strand repairs using 3-0 braided polyester
Sato *et al*. 2013 [31]	Porcine flexor tendon 2 strand modified Kirchmayr–Kessler technique with absorbable 4-0 monofilament polygluconate vs absorbable 4-0 barbed polygluconate. Linear loading tensile strength analyzed.	Tendons repaired by barbed sutures showed greater tensile strength than monofilament sutures.
Peltz *et al.* 2014 [32]	Sheep flexor tendon repaired with 4 strand knotless technique with barbed suture vs 4-strand cross-locked cruciate repair method (Adelaide repair) with knot. Dynamic test for gap formation and failure analyzed.	The barbed suture repair group showed higher resistance to gap formation throughout the test. Final failure force was higher for the barbed suture group compared with the conventional repair group. Barbed suture superior to Conventional suture repair.
Joyce *et al*. 2014 [33]	Porcine flexor tendon 4 strand knotless barbed suture repair vs 4 strand Adelaide repair. Linear loading tensile strength and cross section area analyzed.	Tensile strengths between both tendon groups were very similar. There was a significant reduction in the cross-sectional area in the barbed suture group after repair compared with the Adelaide group.
Grady *et al.* 2015[34]	Chicken flexor tendon 4 strand knotless barbed suture repair vs 4 strand Adelaide repair. Linear loading tensile strength and histology analyzed.	Histologically no inflammation and foreign body reaction in barbed suture repair.
Clemente *et al.* [35] 2015	Porcine flexor tendon 4 strand new repair with barbed suture PDO and prolene vs 4 strand Kessler repair with prolene suture. Analysis of cross section area breaking strength.	Lesser cross section area with barbed suture repair. Significant increase in 2-mm gap formation force(40-50N) and in breaking force(50-60N) with barbed sutures
Nayak *et al*. [36] 2015 (In press)	Human cadaveric Zone 2 laceration of FDP created and repaired with barbed suture vs braided prolene suture. Analysed for cross section area, gliding resistance, strength and work of flexion.	Similar cross sectional area gliding resistance and work of flexion between repairs. Average 1-mmgap formation force with the knotless barbed suture (52 N) was greater than that of the traditional braided suture (43 N).

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