Original Article

Does Suture Depth Affect the Pull-Out Strength of Supraspinatus Repair? A Cadaveric Model

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Background: The strength of a supraspinatus tendon repair depends on many factors. One factor, the distance from the suture-bite to the lateral edge of the repaired tendon, has never been biomechanically evaluated.

Objective: The more medial suture depth to the repaired supraspinatus tendon could obtained the better pull-out strength compared to the lateral suture-depth distance.

Materials and Methods: Six paired human supraspinatus tendons were harvested and were randomly assigned to be repaired with Fiberwire® No. 2 at different suture depths (distance from the lateral tendon edge to the suture bite). Biomechanics properties were tested and modes of failure were noted.

Results: All characteristics of the tendon specimens were normal. Load to failure was found to be proportional to the suture depth by 19.65 N/mm displacement. A suture depth of 15 mm had the highest load to failure at 275.1$\pm$10.5 N (*p*-value <0.01). The mode of failure in two of the six 15 mm specimens was suture breakage; the remaining four specimens failed at the suture-tendon interface.

Conclusion: A suture bite located 15 mm from the lateral tendon edge provides the best possible biomechanical properties with the lowest failure rate. The most common mode of failure is pull-out at the suture-tendon interface.

Keywords: Supraspinatus tendon repair, Suture depth, Pull-out strength, Mode of failure

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The most common cause of shoulder pain in adults is degenerative rotator cuff tear(1). The prevalence of rotator cuff tears increases with age, with up to 20 to 30% of patients aged greater than 60 years(1,2). The gold standard of treatment is rotator cuff repair. Both open and arthroscopic techniques are used for rotator cuff repairs. Patient, equipment, and surgeon factors affect the outcome of rotator cuff repair. Patient factors include age, tendon quality, tear size, and bone quality. Equipment factors include the type of suture and anchor materials. Surgeon factors are surgical repair technique and surgical skill(3-6).

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Arthroscopic rotator cuff repair has become a more popular method for treatment of rotator cuff tear(6). There are many arthroscopic techniques and different types of surgical equipment available to repair the rotator cuff. Although arthroscopic surgery can significantly improve shoulder function, several studies have reported a high rate of re-tear after rotator cuff repair(7,8). There are three interfaces which can affect the incidence of re-tear of rotator cuff repairs: the tendon-suture interface, the suture-anchor interface, and the anchor-bone interface. Cummins et al reported that the most common mode of failure or re-tear was the tendon pulling through the suture suggesting that the weakest link is the tendon-suture interface(7).

Suture depth is defined as the distance between the point where the tendon is sewed and the lateral edge of the torn tendon. This distance is the most important factor for improving strength at the

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tendon-suture interface. Ponce et al reported that a difference in tissue bite size of as little as 5 mm could produce a significant increase in strength of all stitch biomechanics(9). The relationship between suture depth and pull-out strength of the rotator cuff repair, however, is unclear. We hypothesized that greater suture depth would increase the pull-out strength at the tendon-suture interface.

Objective

The purpose of this study was to evaluate biomechanical properties of different suture depths and including pull-out strength in rotator cuff repairs.

Material and Methods

Six fresh frozen cadavers were obtained from the Department of Anatomy, Faculty of Science, Mahidol University. Twelve intact supraspinatus tendons were identified in those soft cadavers and were detached from the proximal humerus at the insertion point (medial footprint) 1 centimeter medial to the musculotendinous junction. The length (medial-lateral), width (anterior-posterior), and thickness (superior-inferior) of the tendons were measured. Specimens were randomized to different suture depth groups and obtained the for biomechanical testing of pull-out strength. The tendons were sutured with a simple stitch using Fiberwire No. 2 (Arthrex, Naples, FL, USA) at 5 mm, 10 mm, or 15 mm from the edge of insertion using 18 gauge needles as the suture passing instrument. The proximal end of the tendon graft was fixed using a custom-made clamp and the suture was tied with a 3 cm loop with a Duncan sliding knot and 6 half-hitches stitches on the metal bar as shown in Figure 1. An Instron universal testing machine (Instron, Grove City, PA, USA) was used to measure pull-out strength. The specimens were given a 5 N pretension load. Then the load was increased to failure under displacement control at the rate of 1 mm/s. The load-displacement curve was recorded until failure; the peak load and failure mechanism of all specimens was recorded. The peak load was considered as the ultimate load to failure in all specimens.

Statistical analysis

One-way analysis of variance was used to determine the effect of suture bite distance on the pull-out strength of the specimens. Statistical significance was set at $p<0.05$. Linear regression was used to analyze the relationship between force and suture depth. Statistical analysis was performed using Stata 13 software.

Results

Cadaveric specimens

The supraspinatus tendon specimens were randomly assigned for repair to each group (5 mm, 10 mm, and 15 mm from the edge of insertion); there were no differences in the width, length, or thickness of the tendons. The average tendon width (anterior to posterior) was 28±4 mm (range: 22 to 34 mm), average tendon length (medial to lateral) was 23±3 mm (range: 18 to 26 mm), and average tendon thickness was 4±0.9 mm (range: 3 to 6 mm) (Table 1).

Load to failure

The ultimate load to failure of specimens by depth are shown in Table 2. The 15-mm suture depth had a significantly greater load to failure than either

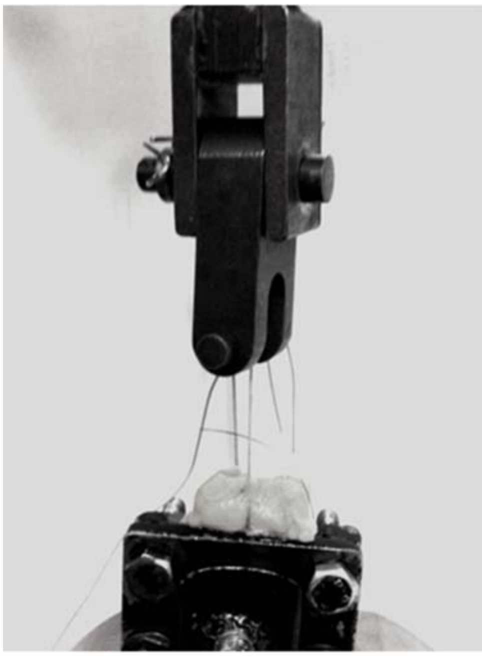

Figure 1. Custom-made clamp with specimen in a universal testing machine.

Table 1. Supraspinatus tendon specimen dimensions

Tendon width (mm) (mean ± SD)	Tendon length (mm) (mean ± SD)	Tendon thickness (mm) (mean ± SD)
28±4	23±3	4±0.9

the 10-mm or the 5-mm suture depths (p-value <0.01). Linear regression analysis showed that the load to failure was proportional to the suture depth. For every one millimeter increase in the distance of the suture depth, the load to failure increased by approximately 19.65 N (Figure 2).

Mode and location of failure

In the load failure test, in ten of the specimens the suture cut through the tendon. Suture breakage occurred in two specimens in the 5 mm suture depth group.

Discussion

The most common mode of failure in rotator cuff repairs is the suture cutting through the tendon, that is, the tendon-suture interface is the weakest link. In the two specimens of the 5-mm suture depth group that failed due to suture breakage, the suture had less tendon tissue bite which may have been the ultimate cause of the failure.

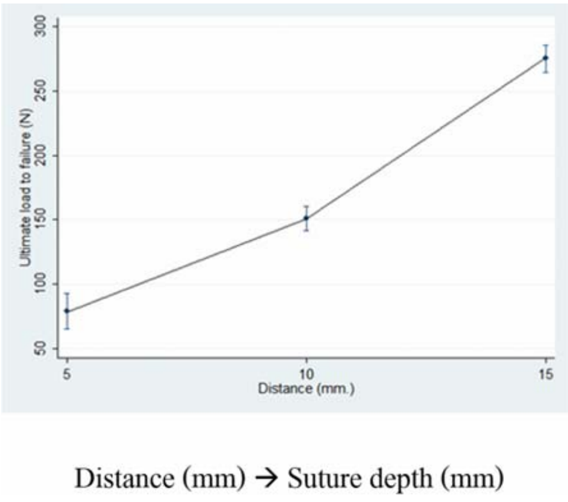

Figure 2. Graph of ultimate load to failure versus suture depth.

Table 2. Load to failure of specimens

Depth (mm)	Load to failure (n) (mean ± SD)	p-value*
5	78.7±13.8	<0.01
10	151.1±9.5	<0.01
15	275.1±10.5	<0.01

* ANOVA - Bartlett's test for equal variances with Bonferroni method

There are many factors which affect the strength of the tendon-suture interface. A tissue penetrating instrument with a smoother tip used with a tapered needle creates smaller holes, thus improve holding strength[9,10]. An arthroscopic stitch configuration type-there are various types of arthroscopic stitches which can improve the pull-out strength of arthroscopic rotator cuff repairs such as the modified Mason-Allen stitch, the massive cuff stitch, and the self-cinching stitch[11-13]. According to a report by Ponce et al[9], an increase in tissue bite size of as little as 5 mm can significantly increase tendon-holding strength. That study concluded that the strength of the rotator cuff stitches was significantly affected by the size of the tissue-penetrating instrument as well as the size of the bite. However, the Ponce study was conducted using infraspinatus tendons of sheep that was different from our study which conducted in the human supraspinatus tendon specimens used in the current study.

We evaluated the association between bite size and strength of the tendon-suture interface. We controlled for the type of penetrating instrument and stitch type so we could evaluate exclusively the affect of suture depth (bite size) on the pull-out strength of the supraspinatus tendon. Our results showed that a 15 mm depth yielded nearly 2 times the strength of a 10 mm depth.

There are two types of penetrating instruments, antegrade and retrograde. There is no limit to the bite size with retrograde penetrating instruments, while antegrade penetrating instruments have a limit of 10 to 15 mm from the tendon edge depending on thickness of the tendon. In our study, a 10 to 15 mm bite size was found to have a pull-out strength >150 N which is greater than the load to clinical failure of sliding knots with 3 to 4 reverse half-hitches with alternating post that are regularly used in arthroscopic rotator cuff repair[14,15]. The biomechanics of the relationship between knot type and suture depth should be studied as well.

The bite should generally be 10 mm from the tendon edge, although there are several reports stating that sutures should be passed through the tendon 10-15 mm medial to the tendon edge[16-19]. Locating the suture medially is done in the double row repair technique to help increase contact surface area and to restore the supraspinatus footprint. This is also the advantage aspect which highlights the importance of medialized suture technique.

Disadvantages of a large bite size include increased tension and excursion of the tendon. A medialized suture increases tissue tension and may also increase the re-tear rate and the incidence of other poor functional outcomes(19,20). The cause of a re-tear may be a larger area of microcirculation disturbance caused by the large bite size which can occur even when using a double row repair.

This study has some limitations. Harvested intact cadaveric supraspinatus tendons may not be representative of an injured tendon. However, using cadaveric specimens more closely resembles human rotator cuff tendons than does using animal tendons. Another limitation was the small size of the study which was limited by the availability of cadaveric specimens, although the study did find statistically significant differences in the pull-out strength of sutured tendons at different depths.

Conclusion

Suture depth significantly influences the ultimate tensile strength of cadaveric supraspinatus tendons The medialized suture technique is the best option to maximize pull-out strength of a repaired tendon.

What is already known on this topic?

A number of biomechanical characteristics of different suture techniques have been conducted, although knowledge of the medial-lateral distance of the suture that provides the maximum pull-out strength was not known.

What this study adds?

This study demonstrates that a suture depth of 15 mm provides maximum pull-out strength for supraspinatus tendons and that the medialized suture technique is the best option for repairing a supraspinatus tendon in terms of pull-out strength.

Potential conflicts of interest

The authors declare no conflict of interest.

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