Knee Surg Sports Traumatol Arthrosc (2015) 23:2661–2666
DOI 10.1007/s00167-014-3128-9

SHOULDER

Biomechanical consequences of proximal biceps tenodesis stitch location: musculotendinous junction versus tendon only

Ulrich J. Spiegl · Sean D. Smith · Simon A. Euler · Peter J. Millett · Coen A. Wijdicks

Received: 10 March 2014 / Accepted: 4 June 2014 / Published online: 27 June 2014

Abstract
Purpose The purpose of this study was to determine the biomechanical effects of placing the biceps tenodesis stitch at the musculotendinous junction versus in the tendon only. Placing the stitch at the musculotendinous junction was hypothesized to result in a significantly weaker repair than stitching in the tendon only.
Methods Testing was performed on two groups of six matched pairs of long head of the biceps (LHB) with enclosed musculotendinous junction and muscle belly. Specimens were randomly distributed between two groups. The same baseball whipstitch configuration was performed using the same suture material in both groups. In group 1, the stitch configuration started 1 cm proximal of the musculotendinous junction (tendon tissue only). For contralateral specimens, the baseball whipstitching included the distal 1 cm of the musculotendinous junction. Specimens were pulled to failure at a rate of 60 mm/min. Ultimate failure load and failure pattern were recorded.
Results Average ultimate failure load of group 2 was significantly higher than group 1 (mean increase 18.6 %, range −9.7 to 35.8 %; $p = 0.046$). A cut-through failure pattern was observed for all specimens in both groups. There were highly significant correlations between ultimate failure load and tendon thickness ($p = 0.004$, $\tau = 0.636$), age of the specimen ($p = 0.002$, $\tau = 0.724$), and gender ($p = 0.004$, $\tau = -0.739$). No significant difference between the groups regarding tendon diameter was observed.
Conclusions Baseball whipstitching of the LHB including the distal part of the tendon and the musculotendinous junction was stronger than sutures placed in the tendon alone. These results suggest that suture pattern affects initial strength of repair, and therefore may affect decisions regarding early post-operative rehabilitation or ultimate clinical outcomes. Inclusion of the musculotendinous junction should be considered clinically for improved time zero strength of the repair construct.

Keywords Biceps tenodesis · Musculotendinous junction · Stitch location · Baseball whipstitch

Introduction

Studies have shown excellent results after subpectoral biceps tenodesis for the treatment of disorders of the long head of the biceps (LHB) [6–8, 13]. While reported complications are low with subpectoral tenodesis, there have been reported failures clinically with loss of fixation and the development of a Popeye deformity [8]. The senior surgeon (P.J.M.) has observed cases where the fixation screw and LHB tendon remained attached to the proximal humerus but there appeared to be a failure distal to the initial tenodesis site.

Several studies have described the fixation strength of the biceps tenodesis construct using interference screws,

Investigation performed at the Department of BioMedical Engineering, Steadman Philippon Research Institute.

U. J. Spiegl · S. D. Smith · S. A. Euler · P. J. Millett · C. A. Wijdicks (✉)
Steadman Philippon Research Institute, 181 W. Meadow Drive, Ste. #1000, Vail, CO 81657, USA
e-mail: cwijdicks@sprivail.org

U. J. Spiegl
Department of Trauma and Reconstructive Surgery, University of Leipzig, Leipzig, Germany

P. J. Millett
The Steadman Clinic, Vail, CO, USA

suture anchors or other fixation devices [2, 5, 10, 11]. However, no study has investigated the effect of the stitch location on suture–tendon construct strength. The musculotendinous junction of the LHB, which is defined as the region between the proximal tendinous region and distal muscle belly, consisting of both tendon and muscle tissue, was reported to be 2 cm from the superior boarder and about 3 cm proximal from the inferior border of the pectoralis major tendon [3, 4]. Based on the close anatomic relationship between the musculotendinous junction and the subpectoral region, incorporation of the musculotendinous junction in the tenodesis stitching during subpectoral biceps tenodesis is a reasonable surgical option. Understanding the effect of stitch location on the time zero suture–tendon construct strength is useful information clinically, as the stitch location can be adjusted intraoperatively to improve construct strength.

The purpose of this study was to determine the effect of stitch location on the ultimate failure strength of the suture–tendon interface for biceps tenodesis. Placing the stitch at the musculotendinous junction was hypothesized to result in a significantly weaker repair than stitching in the tendon only.

Materials and methods

A total of six matched pairs ($n = 12$) of fresh-frozen human cadaveric shoulders (3 males, 3 females, mean age 51 years, range 44–56 years) were used for this study. Specimens were thawed at room temperature 24 h prior to testing. All soft tissues were dissected. The LHB were visually inspected and no preexisting injuries were identified. The LHB tendon was cut 4 cm proximal to the musculotendinous junction, and the muscle belly was cut 5 cm distal of the proximal end of the musculotendinous junction. Institutional Review Board approval was not required because the use of cadaveric specimens is exempt at our institution.

Biomechanical testing

Specimens were randomly distributed between two groups. Paired specimens were prepared with the same stitch configuration in differing locations. A baseball whipstitch configuration with a total of eight throws with a pitch of 5 mm between sutures was performed in all specimens. No. 2 long-chain ultra-high molecular weight polyethylene (UHMWPE) suture core with a braided jacket of polyester and a tapered needle (26.5 mm, ½ circles) (FiberWire, Arthrex Inc., Naples, FL) was used. Both ends of the baseball whipstitch were tied around a 20-mm-diameter rod using 10-half slings each, creating loops later used to load the repair construct during biomechanical testing. In group 1 (3 left, 3 right, mean tendon width: 4.8 mm; range 4.0–5.8 mm), the baseball whipstitch configuration ended 1 cm proximal to the musculotendinous junction,

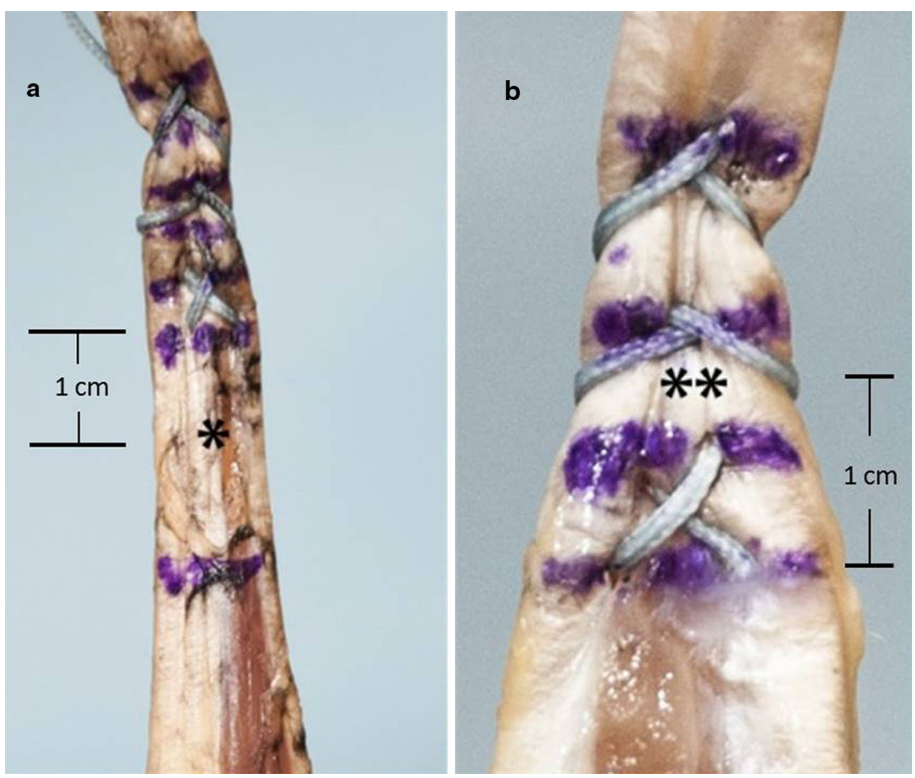

Fig. 1 Depicted is the biceps tendon whipstitch configuration using baseball stitches consisting of four throws with a constant pitch of 5 mm. **a** The stitch is located at the distal tendon only, starting 1-cm proximal of the end of the musculotendinous junction (*single asterisk*). **b** The stitch includes the proximal 1 cm of the musculotendinous junction (*double asterisk*) and the distal part of the tendon

incorporating tendon tissue only. In group 2 (contralateral side) (3 left, 3 right, mean tendon width: 5.1 mm; range 3.5–6.3 mm), the baseball whipstitch configuration incorporated the proximal 1 cm of the musculotendinous junction tissue (Fig. 1). Biomechanical testing was performed using a dynamic tensile testing machine (ElectoPuls E10000, Instron Inc., Norwood, MA). The accuracy for this system has been calibrated and verified to be equal to or better than ±0.25 % of the indicated force. Three centimetres of the distal muscle bellies of each specimen was fixed in a custom clamp, which was rigidly fixed to the base of the test frame (Fig. 2). The proximal 2 cm of the musculotendinous junction were free of the clamping device in all specimens. Specimens were preloaded with a tensile force of 5 N for 2 min and then pulled to failure at a rate of 60 mm/min. Ultimate failure load and the tendon width 4 cm above the proximal end of the musculotendinous junction were recorded for every specimen. Tendon thickness was assessed with digital calipers (Swiss Precision Instruments, Inc., Garden Grove, CA) with a manufacturer reported accuracy of 0.03 mm by a single investigator (U.J.S.).

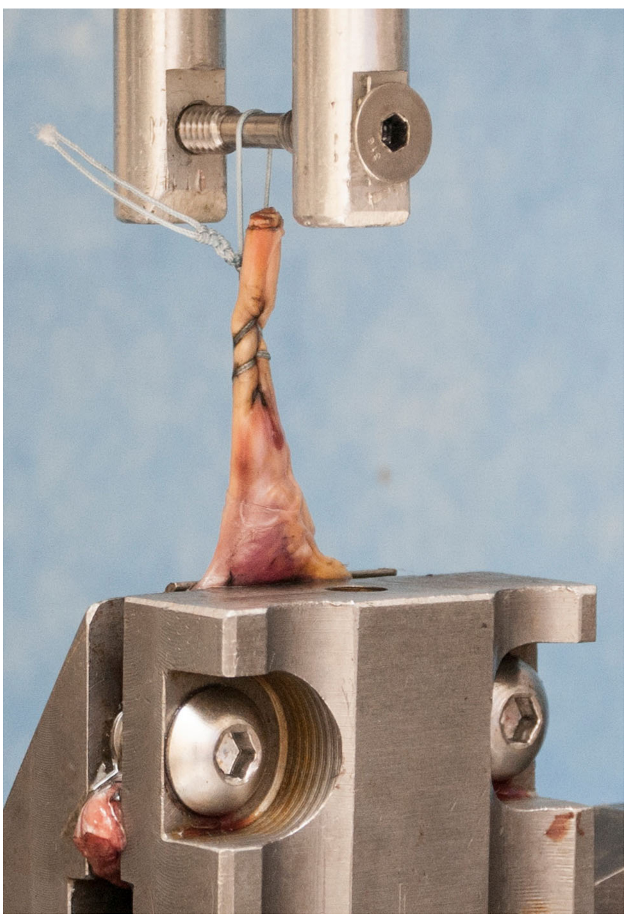

Fig. 2 Study set-up: the muscle belly is fixed to a clamping device. The proximal 2 cm of the musculotendinous junction are free of clamping. Both ends of the stitch suture were tied in a loop with a consistent diameter of 20 mm, which were used to load the repair construct

Statistical analysis

Wilcoxon signed-rank test was used to compare central tendency between groups and Kendall's tau (τ) was used to assess correlation. Statistical significance was declared for $p < 0.05$. All statistical analyses were performed using statistical analysis software (SPSS Version 20, IBM Inc., Chicago, IL).

Results

The results are summarized in Table 1. There were no significant differences between the groups regarding tendon diameter and side. Ultimate failure loads varied highly, both across all specimens, and within study groups [group 1 (tendon only): mean 143 N, median 152 N, range 72–186 N; group 2 (tendon including musculotendinous junction): mean 167 N, median 161 N, range 91–239 N]. In contrast to our pre hoc hypothesis, baseball whipstitching including the proximal part of the musculotendinous junction had significantly higher ultimate failure loads compared to those which were located further proximal in the tendon tissue only (mean 18.6 %, range −9.7 to 35.8 %; $p = 0.046$) (Fig. 3). Ultimate failure loads of each specimen in relation to the stitch location are illustrated in Fig. 4. Superior strength was observed in five of the six specimens (83 %) of group 2. A saw-through failure of the suture through the tissue was observed for all specimens at the distal end of the baseball whipstitch sutures. There were highly significant correlations between ultimate failure load and tendon thickness ($p = 0.004$, $\tau = 0.636$), age of the specimen ($p = 0.002$, $\tau = 0.724$), and the gender ($p = 0.004$, $\tau = -0.739$). Specifically, ultimate failure load increased with increased tendon thickness, decreased with increased age, and was higher in male specimens.

Discussion

The most important finding of this study was that suture configurations for LHB which incorporated the proximal part of the musculotendinous junction had higher ultimate failure strengths than a more proximal location involving the tendon tissue only. Therefore, our pre hoc hypothesis was rejected. Additionally, we found a significant correlation between ultimate failure load and tendon width, gender, and the age of the specimen.

Table 1 Failure loads and tendon width of matched pair specimens

Specimen	Age	Gender	Group 1: tendon only			Group 2: MTJ and tendon			Failure load diff (%)
			Side	Width (mm)	Failure load (N)	Side	Width (mm)	Failure (N)	
Pair 1	46	Female	Left	4.1	110	Right	5.9	131	19.1
Pair 2	50	Female	Right	4.4	128	Left	4.9	154	20.3
Pair 3	56	Male	Right	5.4	176	Left	6.3	239	35.8
Pair 4	56	Male	Left	5.2	186	Right	4.7	168	−9.7
Pair 5	52	Male	Right	5.8	183	Left	5.3	219	19.7
Pair 6	44	Female	Left	4.0	72	Right	3.5	91	26.4
Mean	50.7	–	–	4.8	143	–	5.1	167	18.6
SD	4.6	–	–	0.8	47	–	0.7	55	12.9

(*MTJ* musculotendinous junction; *Failure Load Diff*: relative difference of the failure loads between the two stitch locations in matched specimens)

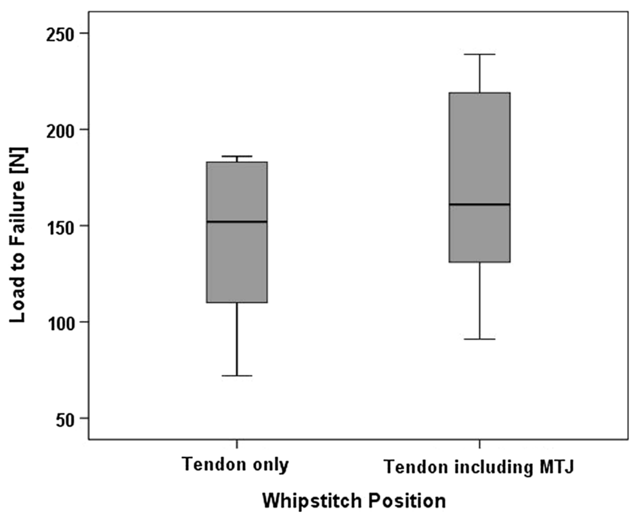

Fig. 3 Comparison of mean suture–tendon interface strength between both stitch locations: tendon only versus tendon including the proximal part of the musculotendinous junction. A significant matched paired difference was observed ($p < 0.05$). (*MTJ* musculotendinous junction)

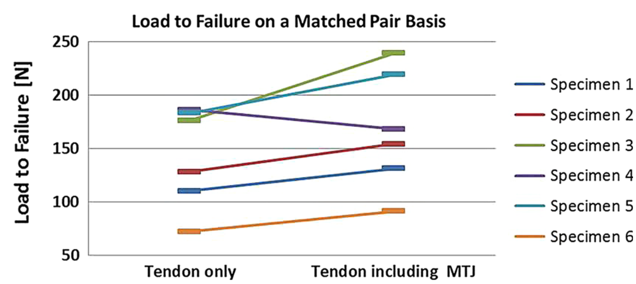

Fig. 4 Ultimate failure loads for each specimen in relation to the stitch location are presented. The ultimate failure load was superior when the stitch included the proximal part of the musculotendinous junction in five of the six specimens. (*MTJ* musculotendinous junction)

The studies by Jarrett et al. [3] and LaFrance et al. [4] have shown the close anatomic relationship between musculotendinous junction of the LHB and the pectoralis major tendon. Thus, extension of the stitch configurations into the MJT is a reasonable surgical strategy in subpectoral biceps tenodesis by placing the suture anchor or tenodesis screw close to the inferior border of the pectoralis major tendon.

The superior suture–tendon interface strength of a baseball whipstitch within the musculotendinous junction may be the result of increased tendon width that is available at the musculotendinous junction, where both muscle tissue and a high percentage of tendon tissue are present. All failures occurred at the tendon–suture interface by a saw-through mechanism. The individual parallel stitches can be placed further apart if an increased tissue width is available. Therefore, a superior stress distribution between the tendon–suture interface can be achieved, resulting in increased overall strength. Similarly, we observed a significant correlation between decreased tendon width and reduced ultimate failure load.

Generally, average ultimate failure loads (group 1: 143 N, group 2: 167 N) were in accordance with the prior literature. Previous reports of ultimate failure loads ranged between 69 N and 187 N after suture anchor tenodesis with failures at the suture–tendon interface, primarily by a saw-through failure mechanism [2, 5, 10]. Golish et al. [2] reported a considerably lower average ultimate failure load of 69 N. However, average age of the specimens (82 years) was substantially higher than the present study, which likely caused inferior tissue quality. In contrast, Patzer et al. [10] reported slightly higher ultimate failure loads (mean 187 N) using a modified lasso-loop stitch. No information on the suture material was reported. Differences in stitch configuration and the suture material may influence the suture–tendon interface strength and cause the slight difference in results. However, the same authors reported an average ultimate failure load of only 111 N after performing biceps tenodesis with suture anchors and the same suture material used in the present study. Considering all reports, the weakest link of a LHB tenodesis with suture anchors seems to be the suture–tendon interface. The improved strength of the suture–tendon interface when including the musculotendinous junction in the stitching has clinical implications, as higher time zero strength of the repair construct can be expected.

With interference screw fixation of the biceps in a bone socket, there may be other factors contributing to the strength of the construct. For example, the interface between biceps tendon and tenodesis screw is reportedly stronger than the tendon–suture interface. Average reported ultimate failure load ranges between 170 and 252 N [2, 5, 10, 11]. In some cases, the LHB tendon might not be fixated by the tenodesis screw. In these cases, the tendon fixation will rely on the suture–tendon interface and the knot strength. Although rare, cases of clinical failures with Popeye deformities have been reported after biceps tenodesis [8].

This study has implicit limitations. First, this study represents a time zero evaluation and does not account for the biological restoration processes. It is also possible that other suture configurations could improve time zero strength. Sakaguchi et al. [12] reported a significant increase of ultimate failure loads by using Krackow stitches compared to baseball whipstitches. Therefore, a higher suture–tendon interface strength might be achieved with a Krackow stitch configuration, possibly avoiding the saw-failure. However, baseball whipstitches represent a common suture stitch configuration used for tendon preparation [1, 9]. Additionally, no conclusions can be drawn on the effect of a further distal stitch location on the strength of the suture–tendon interface. A single thickness measurement was made for each tendon, and therefore, the repeatability of these measurements is unknown and may have contributed some error. However, error was minimized by using a single investigator to perform these measurements. Finally, all baseball whipstitches were performed using the same suture material. It is unknown what effect the suture material might have on the ultimate failure strength of the suture–tendon interface.

The strengths of this study are its matched pair design and the use of a consistent technique, a consistent stitch configuration, and consistent suture material for all specimens; resulting in a well-controlled and reproducible biomechanical model. Additionally, the age of the specimens was comparable to the age of patients who are typically candidates for biceps tenodesis [14]. Further biomechanical studies are necessary to evaluate the effect of different suture materials and a further distal stitch location on the time zero strength of the suture–tendon interface. These results suggest that suture pattern affects initial strength of repair, and therefore may affect decisions regarding early post-operative rehabilitation or ultimate clinical outcomes. Additional clinical studies are needed to determine whether the improved time zero strength of stitching within the musculotendinous junction results in reduced failure rates and improved long-term patient outcomes.

Conclusion

Baseball whipstitching of the LHB within the proximal aspect of the musculotendinous junction and the distal tendon results in improved time zero strength of the suture–tendon interface compared to baseball whipstitching positioned proximal to the musculotendinous junction in the tendon only. When using suture anchors for biceps tenodesis with a whipstitch suture configuration, higher time zero construct strength can be achieved by positioning the stitches within the proximal aspect of the musculotendinous junction. Inclusion of the musculotendinous junction should be considered clinically for improved time zero strength of the repair construct.

Acknowledgments The authors acknowledge Barry Eckhaus for the photos presented in this manuscript. The authors acknowledge Kelly Adair for his laboratory expertise. The authors acknowledge Grant Dornan for his contribution to the statistical analysis.

References

1. Adam F, Pape D, Schiel K, Steimer O, Kohn D, Rupp S (2004) Biomechanical properties of patellar and hamstring graft tibial fixation techniques in anterior cruciate ligament reconstruction: experimental study with roentgen stereometric analysis. Am J Sports Med 32:71–78
2. Golish SR, Caldwell PE 3rd, Miller MD, Singanamala N, Ranawat AS, Treme G, Pearson SE, Costic R, Sekiya JK (2008) Interference screw versus suture anchor fixation for subpectoral tenodesis of the proximal biceps tendon: a cadaveric study. Arthroscopy 24:1103–1108
3. Jarrett CD, McClelland WB Jr, Xerogeanes JW (2011) Minimally invasive proximal biceps tenodesis: an anatomical study for optimal placement and safe surgical technique. J Shoulder Elbow Surg 20:477–480
4. Lafrance R, Madsen W, Yaseen Z, Giordano B, Maloney M, Voloshin I (2013) Relevant anatomic landmarks and measurements for biceps tenodesis. Am J Sports Med 41:1395–1399
5. Mazzocca AD, Bicos J, Santangelo S, Romeo AA, Arciero RA (2005) The biomechanical evaluation of four fixation techniques for proximal biceps tenodesis. Arthroscopy 21:1296–1306
6. Mazzocca AD, Rios CG, Romeo AA, Arciero RA (2005) Subpectoral biceps tenodesis with interference screw fixation. Arthroscopy 21:896
7. Millett PJ, Sanders B, Gobezie R, Braun S, Warner JJ (2008) Interference screw vs. suture anchor fixation for open subpectoral

biceps tenodesis: does it matter? BMC Musculoskelet Disord 9:121
8. Nho SJ, Reiff SN, Verma NN, Slabaugh MA, Mazzocca AD, Romeo AA (2010) Complications associated with subpectoral biceps tenodesis: low rates of incidence following surgery. J Shoulder Elbow Surg 19:764–768
9. Nurmi JT, Sievanen H, Kannus P, Jarvinen M, Jarvinen TL (2004) Porcine tibia is a poor substitute for human cadaver tibia for evaluating interference screw fixation. Am J Sports Med 32:765–771
10. Patzer T, Rundic JM, Bobrowitsch E, Olender GD, Hurschler C, Schofer MD (2011) Biomechanical comparison of arthroscopically performable techniques for suprapectoral biceps tenodesis. Arthroscopy 27:1036–1047
11. Patzer T, Santo G, Olender GD, Wellmann M, Hurschler C, Schofer MD (2012) Suprapectoral or subpectoral position for biceps tenodesis: biomechanical comparison of four different techniques in both positions. J Shoulder Elbow Surg 21:116–125
12. Sakaguchi K, Tachibana Y, Oda H (2012) Biomechanical properties of porcine flexor tendon fixation with varying throws and stitch methods. Am J Sports Med 40:1641–1645
13. Sanders B, Lavery KP, Pennington S, Warner JJ (2012) Clinical success of biceps tenodesis with and without release of the transverse humeral ligament. J Shoulder Elbow Surg 21:66–71
14. Zhang Q, Zhou J, Ge H, Cheng B (2013) Tenotomy or tenodesis for long head biceps lesions in shoulders with reparable rotator cuff tears: a prospective randomised trial. Knee Surg Sports Traumatol Arthrosc. doi:10.1007/s00167-00013-02587-00168