Knee Surg Sports Traumatol Arthrosc (2013) 21:1587–1592
DOI 10.1007/s00167-012-2103-6

SHOULDER

# Stitch positioning influences the suture hold in supraspinatus tendon repair

**Karl Wieser · Stefan Rahm · Mazda Farshad · Eugene T. Ek · Christian Gerber · Dominik C. Meyer**

Received: 6 March 2012 / Accepted: 5 June 2012 / Published online: 17 June 2012


**Abstract**

*Purpose* This study was designed to compare the pull-out strength of simple suture stitches in human supraspinatus tendons with respect to the position of the rotator cable.

*Methods* Fifty-four tests were performed on 6 intact, human supraspinatus tendons, to assess the cutout strength of a simple suture configuration in different positions; medial to, lateral to, or within the rotator cable. Tendon thickness was measured and correlated for each positioned suture.

*Results* Suture positioning lateral to or in the rotator cable showed significantly lower suture retention properties compared with positioning the suture medial to the cable ($p = 0.002$). In all tested specimens, the central stitch in the row medial to the rotator cable provided the optimum retention properties (mean: 191 N; SD: ± 44; $p < 0.01$), even after correcting for tendon thickness.

*Conclusion* This study shows that it is desirable to identify the rotator cable and to pass sutures just medial to it, close to the middle of the tendon, which provided highest possible suture retention properties.

**Keywords** Rotator cuff repair · Suture cutout · Fixation strength · Rotator cable

K. Wieser (✉) · S. Rahm · M. Farshad · E. T. Ek · C. Gerber · D. C. Meyer
Orthopaedic Department, Balgrist Hospital, University of Zurich, Forchstrasse 340, 8008 Zurich, Switzerland
e-mail: karl.wieser@balgrist.ch

## Introduction

Despite important improvements in rotator cuff repair technique, the persistence or recurrence of defects of the repaired cuff remains too frequent [3, 4, 12, 14, 28]. The tendon quality is an important; however, predetermined factor and therefore the surgical technique might further be optimized.

The tendon quality is an important, however predetermined factor, and therefore it may be the surgical technique that needs to be further optimized to improve initial fixation and healing of the tendon to the bone. With the introduction of stronger anchors and modern polyblend suture materials, the suture–tendon interface has been identified as the weakest link of rotator cuff repair [2, 10]. Much research attention has been directed towards improving the biomechanical properties of different tendon grasping techniques [1, 2, 9, 11, 13, 16, 17, 20, 27]; however, there is a paucity of data in the current literature with regard to suture positioning within the tendon.

When sutures cut through a tendon, they tend to slip along the longitudinal orientation of the tendon fibres, analogous to a comb in a bundle of hair. The rotator cuff, however, is architecturally different from most other tendinous structures in the body: First identified by Clark et al. [7, 8] and later described and analysed as a loaded cable in the suspension bridge model by Burkhart and Burkhart et al. [5, 6], the rotator cable is now widely accepted as an independent anatomical structure of the glenohumeral capsulo-ligamentous joint complex. In terms of its origin, the superficial-medial layer arises from the superior facet of the lesser tuberosity and its deep lateral layer from the anterior facet of the greater tuberosity at the anterior edge of the SSP. Forming a semicircular arch, the cable runs perpendicular to the longitudinal axes of the SSP and ISP tendon, reaching the teres minor tendon on the posterior aspect of the greater tuberosity [15]. The rotator cable may be identified visually [7, 8, 15], arthroscopically [6], on MRI [23] or via ultrasonography [21]. Due to its perpendicular orientation, in relation to the fibres of the SSP and ISP tendons, the rotator cable may initially prevent further extension of a rotator cuff tear, which generally starts at the rotator crescent, a region of relative tendon weakness and hypovascularity lateral to the rotator cable [6].

The hypothesis of the present investigation was that the rotator cable, as a perpendicular structure to the tendon axis, could represent an important structural resistance against suture cutout, which could be exploited in cuff repair. This study was therefore designed to compare the cutout strength of a simple suture configuration in human supraspinatus tendons positioned medial, within, or lateral to the rotator cable.

## Materials and methods

Two orthopaedic surgeons performed the dissections, preparations and repairs after thawing 10 fresh frozen (−20°) human shoulders for 24 h at room temperature. The specimens were stripped of all soft tissues except for the supraspinatus muscle and tendon. This tendon was sharply detached from its insertion site at the greater tuberosity of the humerus. Specimens were kept moist with 0.9 % saline during dissection, preparation, and mechanical testing. The scapula was set into a fixation device (Fig. 1). Four specimens had to be excluded due to partial or visible damage of the tendons and were used for preliminary testing. Fifty-four tests were performed on 6 (3 left and 3 right) shoulders, with no preexisting rotator cuff abnormalities on macroscopic examination.

The rotator cable was identified on the articular side of the supraspinatus tendon and stitch positioning was determined. Precise stitch positions are depicted in Fig. 2. First four lateral sutures were set 5 mm medial to the free lateral tendon margin. The most anterior suture was set in the anterior part of the rotator cable; the three following sutures were positioned lateral to the rotator cable (lateral row: antero-central, postero-central, and posterior). Simple stitches, piercing the width of the tendon using a braided nonabsorbable polyblend UHMWPE suture (USP No. 2) (FibreWire, Arthrex Inc., Naples, FL), were used to minimize variability in technique. Sutures were securely fixed to a 1,000 N load cell, forming a suture loop using 7 square knots. Following separate load to failure tests for every single suture starting from anterior to posterior, the tendon end was resected leaving 5 mm of the rotator cable and the second suture row was placed. Three sutures were positioned (anterior, central and posterior) exactly medial to the rotator cable (5 mm medial to the free lateral tendon margin). Analogous tests were performed. After repeated resection of tendon, one anterior and one posterior stitch were set medial to the musculotendinous junction again exactly 5 mm away from resection line and the same test protocol was performed. The thickness of the tendon (mm) and the distance to the myotendinous junction (mm) was measured for every positioned suture with a caliper.

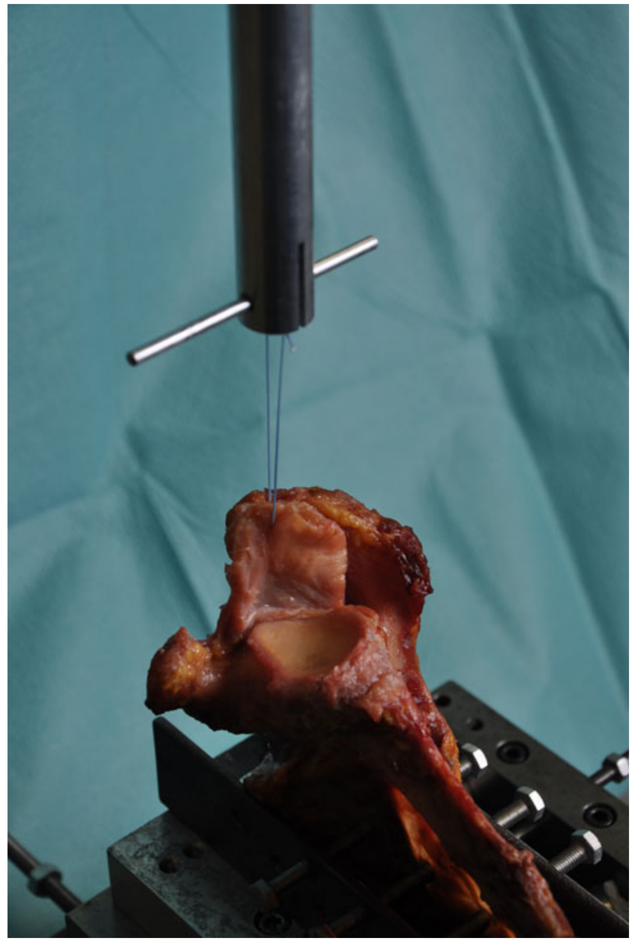

**Fig. 1** Biomechanical test setting: The prepared scapula was set into a fixation device. Each suture was set 5 mm medial to the free lateral tendon margin. Sutures were securely fixed to a 1,000-N load cell of the material testing machine (Zwick-Roell, Ulm, Germany), forming a suture loop using 7 square knots. Ultimate load to failure test was performed at a rate of 1 mm/s

The investigations were performed using a material testing machine (Zwick-Roell, Ulm, Germany), which recorded the data with the dedicated software (testExpert 10, Zwick-Roell, Ulm, Germany) and evaluated the data regarding load (N) and displacement (mm), which were digitally recorded and the deformation curve and the mode of failure was documented. After preloading the system with 5 N, an ultimate load to failure test was performed at a rate of 1 mm/s. Failure of the suture–tendon complex was defined as suture cutout through the remaining 5 mm tendon substance.

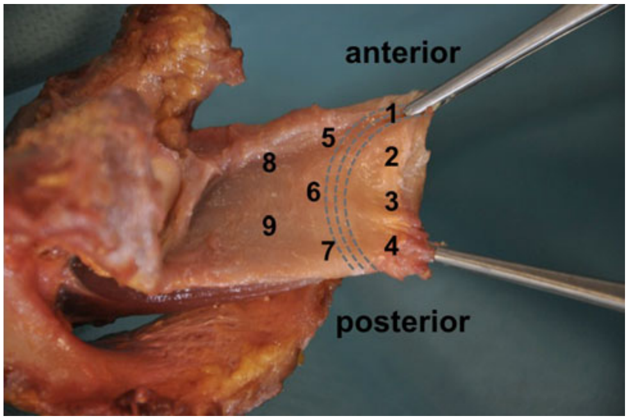


**Fig. 2** Articular side of a supraspinatus tendon with illustration of suture placement in relation to the rotator cable. Sutures pierced the tendon and were placed in three rows 5 mm medial to the resected free tendon margin: Antero-lateral in the cable (*1*). Lateral to the cable: antero-central (*2*), postero-central (*3*), and posterior (*4*). Medial to the cable: anterior (*5*), central (*6*), and posterior (*7*). Medial to musculotendinous junction: anterior (*8*) and posterior (*9*)

Statistical analysis

Statistic analysis was performed with a commercial software package (PRISM, Version 4 for Macintosh, Graphpad Software Inc.) A two-way ANOVA for repeated measure with post hoc Dunnett's multiple comparison was performed to evaluate strength of the different suture positions. Correlation between tendon thicknesses to strength was calculated using Spearman's rank correlation. Level of significance was set at $p < 0.05$.

## Results

The mode of failure was suture cutout of the tendon in all specimens. Scapula fracture, muscle rupture, knot slippage, or suture breakage were not observed. The mean force to failure, standard deviations, and the lowest value as well as mean tendon thickness are presented in Table 1. In all specimens, the central stitch in the row just medial to the rotator cable provided highest suture retention properties (mean: 191 N; SD: ± 44; $p < 0.01$) (Fig. 3a).

Suture positioning lateral to or in the rotator cable showed significantly lower suture retention values compared to suture positioning medial to the cable ($p = 0.002$). Suture positioning medial to the myotendinous junction provided almost equal properties as lateral tendon stitches.

Mean distance to the myotendinous junction decreased continuously from anteriorly to posteriorly and measured 21 and 15 mm for the lateral and middle suture row, respectively.

Thickness of the tendon revealed a correlation to suture retention properties ($p < 0.001$; $r = 0.63$). Therefore, tendon thickness was correlated as a confounding factor for every stitch of the lateral and middle row. Although the thickness has a confounding influence, it did not change the results with respect to the superior pullout strength of a medial suture position. The differences between medial and lateral suture positioning decreased slightly in this analysis; however, the difference between suture positioning antero-lateral in the cable and medial to cable became even more pronounced (Fig. 3b).

## Discussion

The most important finding of this study was that in all tested specimens, suture positioning medial to the rotator cable provided the best retention properties, even after correcting for tendon thickness. This article was intended to aid surgeons in determining optimal stitch positioning in arthroscopic rotator cuff repair. It shows that it is desirable to identify the rotator cable and to pass sutures just medial to it, close to the middle of the tendon to provide highest possible suture retention properties for initial fixation of a

**Table 1** Forces to failure and tendon thickness

| | In the cable | Lateral to the cable | | | Medial to the cable | | | Medial to musculotendinous junction | |
|---|---|---|---|---|---|---|---|---|---|
| | Anterior | Antero-central | Postero-central | Posterior | Anterior | Central | Posterior | Anterior | Posteior |
| Force to failure (*N*) | | | | | | | | | |
| Mean | 91 | 97 | 79 | 49 | 132 | 191 | 96 | 94 | 106 |
| SD | 34 | 22 | 19 | 22 | 29 | 44 | 23 | 36 | 33 |
| Range | 54–138 | 70–121 | 62–112 | 20–72 | 98–170 | 148–263 | 63–130 | 35–135 | 70–150 |
| Tendon thickness (mm) | | | | | | | | | |
| Mean | 3.5 | 2.6 | 2.3 | 1.6 | 3.1 | 3.3 | 2.2 | | |
| SD | 0.8 | 0.4 | 0.4 | 0.4 | 0.6 | 0.4 | 0.4 | | |

The mean force to failure, the standard deviation, the lowest value of each suture position, as well as the mean tendon thickness and the corresponding standard deviation are shown

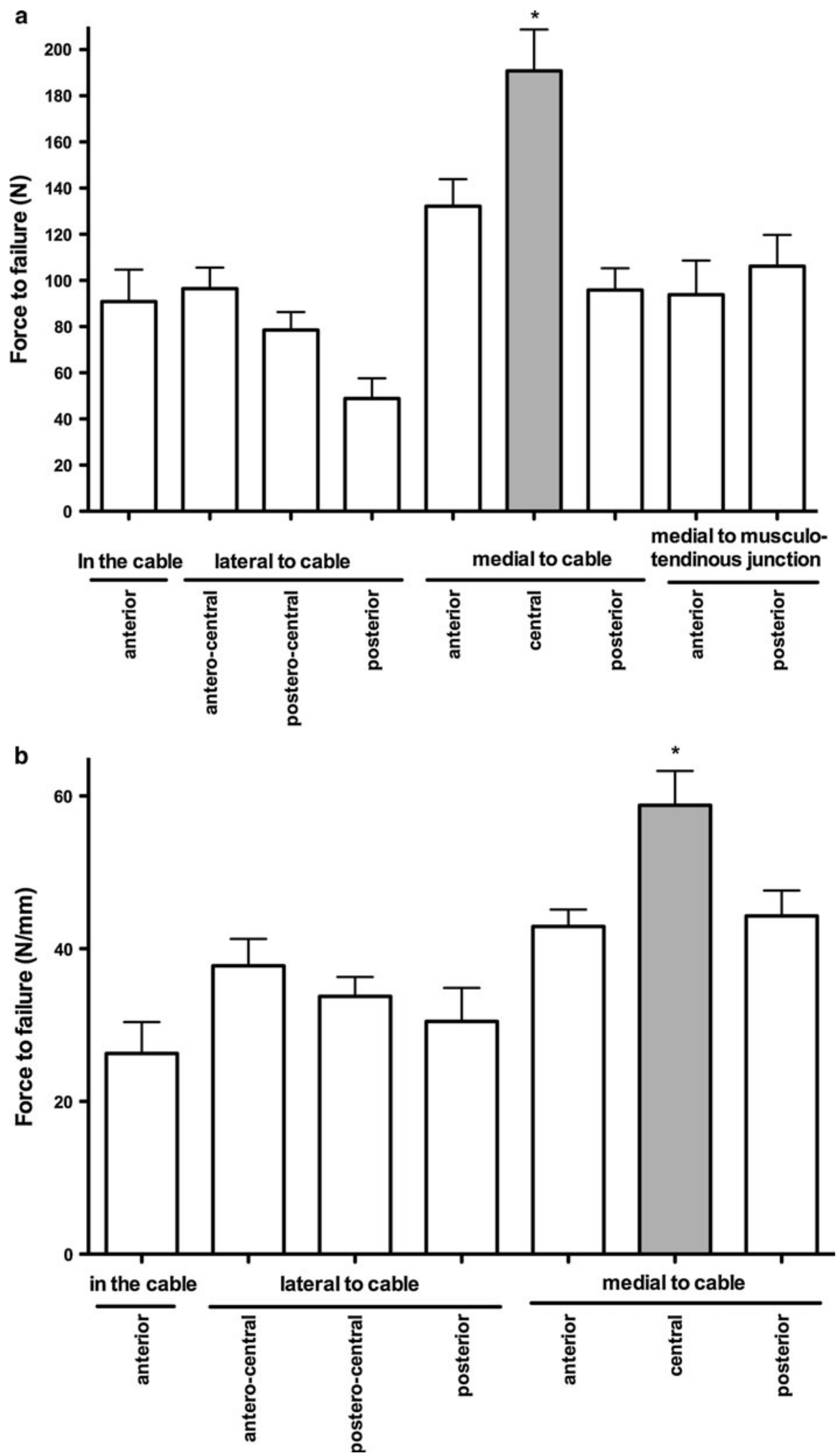


**Fig. 3** Suture retention properties without (**a**) and with correlation of tendon thickness (**b**). Intermuscular stitches were not correlated for thickness. In all specimens, the central stitch in the row just medial to the rotator cable provided highest suture retention properties, compared to all other stitches ($p < 0.01$). After correction for tendon thickness, the differences in suture retention were less pronounced. Still significant differences were found with the best retention properties for the central stitch medial to the rotator cable

supraspinatus tendon repair. Suture positioning lateral to or in the rotator cable showed significantly lower suture retention properties compared with positioning the suture medial to the cable.

It is not uncommon to observe sutures pull through a tendon along the length of its fibres with relatively little resistance. The hypothesis that suture placement into or medial to the rotator cable provides better suture retention properties can be confirmed in part. In all tested specimens, the central stitch in the intermediate row, medial to the rotator cable, provided the best suture retention properties, before and after correction for tendon thickness, which is a recognized confounding factor. Interestingly, suture retention decreased rapidly with a more posterior suture position, consistent with the reduced tendon thickness in this posterior region, where one of the five tendon layers is missing [7]. Although we found a good correlation for tendon thickness and suture retention, the thickest region of the tendon in the antero-lateral aspect did show unexpectedly low values until suture cutout occurred. This might be a consequence of the semicircular course of the cable, which anteriorly bends into a more parallel course with the main tendon fibres. However, in the middle portion of the tendon, the perpendicular course of the cable fibres provides the best resistance against the cutting sutures.

In the case of a massive rotator cuff tear, where the tear extends beyond the rotator cable, a more medial suture position may be the only alternative for suture placement. However, rarely used in clinical situations, due to the fact that such medial suture position will lead to a very tight or even over tensioned rotator cuff repair, we tested the properties of such an intramuscular suture position and found decreased initial fixation strength of almost 50 %, comparable to the best intratendinous suture positions.

To our best knowledge, there is only one article available in current orthopaedic literature, which focused on the regional differences with respect to suture retention properties in human supraspinatus tendons [26]. In this biomechanical investigation, sutures were placed either medial at the myotendinous junction or lateral, close to the free SSP tendon margin. In intact specimens, no difference in load to failure could be detected between medial and lateral suture positioning. As medial suture positioning was independent of cuff integrity, among torn tendons load to failure was significantly lower in the lateral region compared to the medial region. However, in this study, they did not analyse the anatomical relationship of suture positioning and the rotator cable.

Other anatomical studies stated that the anterior SSP tendon, which is more cord like, narrow and longer than the posterior portion [22, 25], might play a more important functional role in rotator cuff repairs because of its superior tensile properties and smaller amount of gapping compared to the posterior tendon following tendon repair [19, 24]. This could be confirmed with our study at least in part, as the anterior stitches in the lateral and intermediate (medial to the rotator cable) row showed higher suture retention properties compared to the posterior ones. However, by far the strongest suture position was in the central part of the tendon exactly medial to the rotator cable, which we believe provides the best restrain against suture cutout following rotator cuff repair.

This study has some limitations. We used healthy tendons and did therefore not consider possible changes to the tendon quality with tears and possible loss of tendon substance and integrity, which may be subject of future studies. Although the rotator cable was impressively well identified in the laboratory setting, we are aware of the fact that this might not always be possible during arthroscopic rotator cuff repair. Furthermore, we did not correlate our results for specimen age, which might not only influence quality of the SSP tendon itself but also limit the structural integrity of the rotator cable. While we did reach statistically significant results with a relatively limited number of tests, we did only investigate ultimate load to failure and not the response to cyclic loading. This might not represent the cyclic loading conditions experienced in vivo but represents as a comparable method of repeated measurements in a single tendon. Nevertheless, these results demonstrate that the position of the suture influences initial fixation strength of a supraspinatus repair, which is in contradistinction to the currently accepted ovine or bovine laboratory models of rotator cuff testing [1, 2, 9, 11, 13, 17, 20].

Further research in this topic should address whether a similar zone of resistance exists in the subscapularis tendon, for instance the so-called “comma sign”, which is created by retraction of the superior subscapularis and the anterior supraspinatus tendon [18], and the resistance of the rotator cable against gap formation under cyclic loading conditions. Furthermore, it will be interesting to study the alterations in the anatomical position and condition of the rotator cable in the case of chronic and retracted tendon tears, as this might impair the possibility of proper suture passage medial to the rotator cable.

## Conclusion

This study shows that it is desirable to identify the rotator cable and to pass sutures just medial to it, close to the middle of the tendon, which provides a potentially strong suture position for initial fixation of a supraspinatus tendon repair.

**Conflict of interest** The authors have no potential conflict of interest.

## References

1. Baleani M, Ohman C, Guandalini L et al (2006) Comparative study of different tendon grasping techniques for arthroscopic repair of the rotator cuff. Clin Biomech 21(8):799–803

2. Baleani M, Schrader S, Veronesi CA, Rotini R, Giardino R, Toni A (2003) Surgical repair of the rotator cuff: a biomechanical evaluation of different tendon grasping and bone suture fixation techniques. Clin Biomech 18(8):721–729
3. Bishop J, Klepps S, Lo IK, Bird J, Gladstone JN, Flatow EL (2006) Cuff integrity after arthroscopic versus open rotator cuff repair: a prospective study. J Shoulder Elbow Surg 15(3): 290–299
4. Boileau P, Brassart N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG (2005) Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? J Bone Joint Surg Am 87(6):1229–1240
5. Burkhart SS (1992) Fluoroscopic comparison of kinematic patterns in massive rotator cuff tears. A suspension bridge model. Clin Orthop Relat Res 284:144–152
6. Burkhart SS, Esch JC, Jolson RS (1993) The rotator crescent and rotator cable: an anatomic description of the shoulder's "suspension bridge". Arthroscopy 9(6):611–616
7. Clark JM, Harryman DT 2nd (1992) Tendons, ligaments, and capsule of the rotator cuff. Gross and microscopic anatomy. J Bone Joint Surg Am 74(5):713–725
8. Clark J, Sidles JA, Matsen FA (1990) The relationship of the glenohumeral joint capsule to the rotator cuff. Clin Orthop Relat Res 254:29–34
9. Coons DA, Barber FA, Herbert MA (2006) Triple-loaded single-anchor stitch configurations: an analysis of cyclically loaded suture-tendon interface security. Arthroscopy 22(11):1154–1158
10. Cummins CA, Murrell GA (2003) Mode of failure for rotator cuff repair with suture anchors identified at revision surgery. J Shoulder Elbow Surg 12(2):128–133
11. Demirhan M, Atalar AC, Kilicoglu O (2003) Primary fixation strength of rotator cuff repair techniques: a comparative study. Arthroscopy 19(6):572–576
12. Galatz LM, Ball CM, Teefey SA, Middleton WD, Yamaguchi K (2004) The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. J Bone Joint Surg Am 86(2):219–224
13. Gerber C, Schneeberger AG, Beck M, Schlegel U (1994) Mechanical strength of repairs of the rotator cuff. J Bone Joint Surg Br 76(3):371–380
14. Jost B, Pfirrmann CW, Gerber C (2000) Clinical outcome after structural failure of rotator cuff repairs. J Bone Joint Surg Am 82:304–314
15. Kask K, Kolts I, Lubienski A, Russlies M, Leibecke T, Busch LC (2008) Magnetic resonance imaging and correlative gross anatomy of the ligamentum semicirculare humeri (rotator cable). Clin Anat 21(5):420–426
16. Kim DH, Elattrache NS, Tibone JE et al (2006) Biomechanical comparison of a single-row versus double-row suture anchor technique for rotator cuff repair. Am J Sports Med 34(3):407–414
17. Koganti AK, Adamson GJ, Gregersen CS, Pink MM, Shankwiler JA (2006) Biomechanical comparison of traditional and locked suture configurations for arthroscopic repairs of the rotator cuff. Am J Sports Med 34(11):1832–1838
18. Lo IK, Burkhart SS (2003) The comma sign: an arthroscopic guide to the torn subscapularis tendon. Arthroscopy 19(3): 334–337
19. Ma CB, Comerford L, Wilson J, Puttlitz CM (2006) Biomechanical evaluation of arthroscopic rotator cuff repairs: double-row compared with single-row fixation. J Bone Joint Surg Am 88(2):403–410
20. Ma CB, MacGillivray JD, Clabeaux J, Lee S, Otis JC (2004) Biomechanical evaluation of arthroscopic rotator cuff stitches. J Bone Joint Surg Am 86(6):1211–1216
21. Morag Y, Jacobson JA, Lucas D, Miller B, Brigido MK, Jamadar DA (2006) US appearance of the rotator cable with histologic correlation: preliminary results. Radiology 241(2):485–491
22. Roh MS, Wang VM, April EW, Pollock LU, Flatow EL (2000) Anterior and posterior musculotendinous anatomy of the supraspinatus. J Shoulder Elbow Surg 9(5):436–440
23. Sheah K, Bredella MA, Warner JJ, Halpern EF, Palmer WE (2009) Transverse thickening along the articular surface of the rotator cuff consistent with the rotator cable: identification with MR arthrography and relevance in rotator cuff evaluation. Am J Roentgenol 193(3):679–686
24. Tashjian RZ, Leventhal E, Spenciner DB, Green A, Flemmin BC (2007) Initial fixation strength of massive rotator cuff tears: in vitro comparison of single-row suture anchor and transosseous tunnel constructs. Arthroscopy 23(7):710–716
25. Volk AG, Vangsness CT Jr (2001) An anatomic study of the supraspinatus muscle and tendon. Clin Orthop Relat Res 384: 280–285
26. Wang VM, Wang FC, McNickle AG et al (2010) Medial versus lateral supraspinatus tendon properties: implications for double-row rotator cuff repair. Am J Sports Med 38(12):2456–2463
27. White CD, Bunker TD, Hooper RM (2006) The strength of suture configurations in arthroscopic rotator cuff repair. Arthroscopy 22(8):837–841
28. Zumstein MA, Jost B, Hempel J, Hodler J, Gerber C (2008) The clinical and structural long-term results of open repair of massive tears of the rotator cuff. J Bone Joint Surg Am 90(11):2423–2431