The Effect of the Angle of Suture Anchor Insertion on Fixation Failure at the Tendon–Suture Interface After Rotator Cuff Repair: Deadman's Angle Revisited

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Purpose: To evaluate what effect the angle of screw-in suture anchor insertion has on fixation stability at the suture–tendon interface. **Methods:** Supraspinatus tendons from 7 matched pairs of human cadaveric shoulders were split, yielding 4 tendons per cadaver. An experimental rotator cuff tear was created and repaired, using a 5.0-mm diameter screw-in suture anchor. In a staggered, matched pair arrangement, the angle of anchor insertion was varied between 45° (deadman's angle) and 90° to the articular surface. Each repair underwent cyclic loading, and 2 failure points were defined: the first at 3 mm of repair site gap formation and the second at the point of complete failure. The number of cycles to failure was compared between the 2 groups. **Results:** The mean number of cycles to 3-mm gap formation for anchors inserted at 90° was 380. This was significantly higher than for repairs made with the 45° angle of anchor insertion (mean, 297 cycles). Complete failure occurred at a significantly greater number of cycles with the 90° anchors (mean, 443 cycles) compared with the 45° anchors (mean, 334 cycles). **Conclusions:** Compared with anchors placed at the current standard of the deadman's angle of 45°, suture anchors placed at 90° to the junction of the greater tuberosity and the humeral head articular surface provided improved soft tissue fixation in an experimental rotator cuff model. **Clinical Relevance:** The angle of suture anchor insertion into the greater tuberosity during rotator cuff repair has an effect on the soft tissue fixation at the tendon–suture interface. **Key Words:** Arthroscopy—Deadman's angle—Rotator cuff repair—Shoulder.

Injuries to the rotator cuff, whether the result of an acute traumatic event or a degenerative tear, often lead to significant shoulder pain and dysfunction.[1-4] When nonoperative management fails, operative rotator cuff repair is undertaken in an effort to restore a pain-free shoulder with normal strength, range of motion, and function.[5] Recent clinical studies have shown that long-term shoulder function after rotator cuff surgery is related to the maintained integrity of the rotator cuff repair.[5-8]

Important factors in the surgical management of rotator cuff tears include delineation of the tear, mobilization of the retracted tendon, and fixation of the tendon to the superior junction of the greater tuberosity and the articular surface of the humeral head.[1,9] Tendon to bone fixation has been accomplished using either transosseous sutures or suture anchor techniques.[10,11] Advances in shoulder arthroscopy have increased the popularity of suture anchor methods for rotator cuff repair, secondary to the ease and speed associated with their use and their decreased surgical exposure and associated morbidity.[12-14] Recent studies

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have shown that arthroscopic rotator cuff repairs produce equally good results and patient satisfaction compared with the well-established mini-open repair technique.[15-17]

The integrity of rotator cuff repairs managed with suture anchor techniques relies on strength at 2 main interfaces, that between the anchor and bone and that between the suture and tendon. Anchor pullout strength is affected by bone quality, anchor design, and implantation technique.[18-20] With respect to implantation technique, many orthopaedic surgeons insert suture anchors at what is termed the "deadman's angle" of ≤45° to the bone surface, to increase resistance to anchor pullout secondary to the tension created by the rotator cuff.[2] The deadman theory of suture anchors was introduced by Burkhart,[21] in 1995, in a mathematical evaluation of the forces involved in rotator cuff repair. Burkhart used trigonometric calculations to suggest that minimizing the angle of insertion of the suture anchor and the angle that the suture makes with the rotator cuff can increase the pullout strength of the anchor and reduce tension in the suture. However, recent in vivo and ex vivo analyses have shown that, with current screw-in suture anchor designs, failure occurs at the suture–tendon interface rather than from anchor pullout, with the suture cutting through the tendon.[22,23] Clinical studies of arthroscopic rotator cuff repairs have reported retear rates ranging from 24% to 94%, as seen on postoperative magnetic resonance imaging scans or ultrasound evaluations.[24-27]

The stable anchor to bone fixation afforded by the new generation of suture anchor design raises the question of whether the deadman's angle theory of anchor insertion still has relevance in rotator cuff repair. The current investigation evaluated the effect that the angle of screw-in suture anchor insertion has on fixation stability at the suture–tendon interface in the setting of experimental rotator cuff repair. We hypothesized that there would be no difference in the number of loading cycles to 3 mm gap formation and the number of cycles to complete failure between repairs made with the anchors inserted at the deadman's angle of 45° and those made with the anchors inserted at 90°.

METHODS

Seven matched pairs of fresh-frozen human cadaveric shoulders were selected (5 male and 2 female donors with a mean age of 48.3 years; range, 35 to 55 years) and radiographic images were taken to exclude any specimens with occult pathology. Dual energy x-ray absorptiometry scanning by means of a Hologic scanner (Hologic, Boston, MA) with a water bath tissue phantom was used to determine bone mineral density. Each specimen was dissected free of soft tissue until only the proximal humerus and the attached supraspinatus tendon remained. Each supraspinatus tendon was split in half to yield 4 tendons per cadaveric pair, 2 associated with the anterior position on the greater tuberosity and 2 associated with the posterior position on the tuberosity. As often as possible during preparation and biomechanical testing, the specimens were covered in saline-soaked gauze to avoid tissue dessication.

Before testing, the humerus was perpendicularly transected at the mid-diaphyseal level with a band saw. The distal end of the specimen was then potted upright in 6 × 20 cm steel square tubing with acrylic cement. Next, a rotator cuff tear was simulated by cutting horizontally across the tendon insertion site on the greater tuberosity with a No. 10 scalpel blade. Each tear was repaired by initially placing a 5-mm Spiralok absorbable threaded suture anchor (Depuy

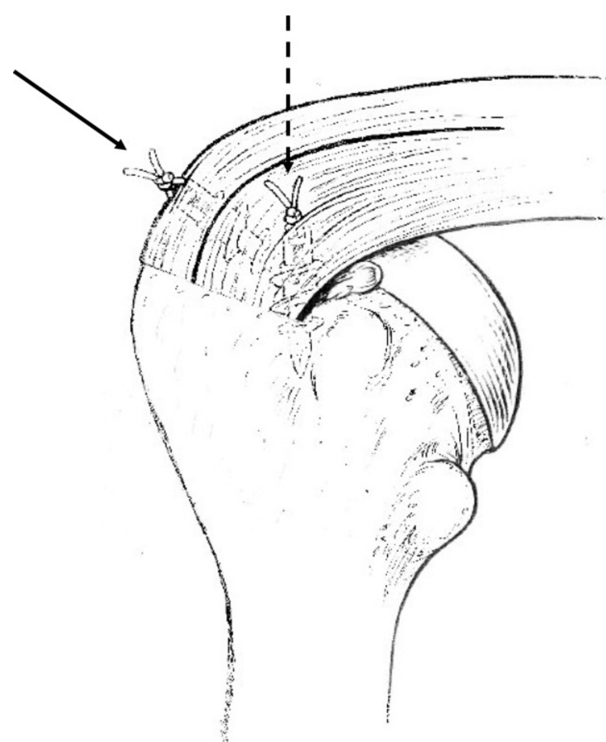

FIGURE 1. Insertion of 5.0-mm Spiralok screw-in suture anchors at "deadman's angle" of 45° (solid arrow) and 90° (dashed arrow) to the superior junction of the greater tuberosity and the humeral head articular surface in a repaired specimen before cyclic loading.

Mitek, Raynham, MA) into either the anterior or posterior position of the greater tuberosity of the humerus, in one of the two selected insertion angles (deadman's angle of 45° or 90° to the junction of the greater tuberosity and the humeral head articular surface; Fig 1). For each matched pair, the randomization was performed by first determining the angle and position of the suture anchors for the right shoulder by selecting a sealed envelope containing one of the two possible combinations of insertion angle and location (posterior 90°/anterior 45° or posterior 45°/anterior 90°). The combination selected for the right shoulder would result in the contralateral shoulder being treated with the opposite combination. This process was repeated for each matched pair.

The angle of anchor placement into the greater tuberosity was standardized with the use of 45° and 90° insertion guides. Each rotator cuff repair was performed in an open setting using an arthroscopic knot-tying technique. A single suture was passed using a free needle 10 mm from the site of the simulated rotator cuff tear, centrally in the tendon. A single surgeon then tied a simple Roeder knot backed by 3 reversing half-hitches on alternating posts, using a No. 2 Orthocord suture (DePuy Mitek; Fig 1).

For biomechanical testing, the potted specimen was securely mounted in an adjustable vise at the base of the Instron 2000 Universal Material Testing Machine (Instron, Canton, MA) so that the repaired tendon could be longitudinally loaded in the anatomic direction of the repaired muscle–tendon unit (Fig 2). The proximal portion of the tendon at the musculotendinous junction was then clamped to the materials testing system (MTS) load cell in a custom-built pneumatic tendon grip. Each specimen was preconditioned with the application of a 5 N tensile load and then cyclically loaded with 90 N (one third of the load that can be delivered by a maximal contraction of the muscles that subtend the cuff defect[22]) at 1 Hz and a rate of 33 mm per second (the reported loading rate that occurs in normal daily activities[13]).

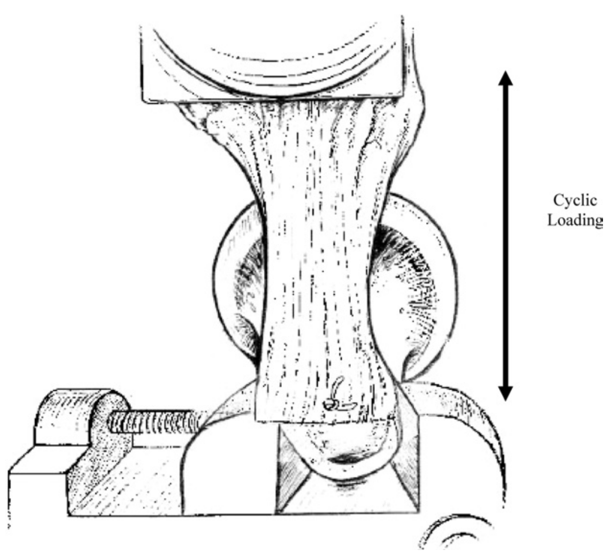

FIGURE 2. Testing of a repaired specimen mounted in an adjustable vise so that the repaired tendon could be longitudinally loaded in the anatomic direction of the repaired muscle–tendon unit.

During cyclic loading, the presence of suture cut through at the tendon–suture interface was noted. Two failure points were defined; the first was the development of 3 mm of gap formation at the repair site and the second was the point of complete failure of fixation. Three-millimeter gap formation is a common definition of clinical failure in the rotator cuff repair literature. If the construct failed by other means, the location of the failure and the number of cycles at which it occurred was documented. Subsequent to repair failure, each suture anchor was evaluated for gross evidence of loosening.

Paired Student *t* tests were then used to make comparisons between the 2 angles of suture anchor insertion with respect to gap formation and complete fixation failure. $P \leq .05$ was considered statistically significant.

RESULTS

Dual energy x-ray absorptiometry scanning of the cadaveric shoulder specimens revealed bone density values in the normal range, with an overall mean of 0.137 g/cm^3 (range, 0.110 to 0.161 g/cm^3). There was no significant difference in bone density between the right and left proximal humeri in our matched pairs ($P = .91$).

Each experimental rotator cuff repair failed in an identical manner during cyclic loading, with the suture loop progressively cutting through the supraspinatus tendon. For the repairs made with the screw-in suture anchor inserted at 90° to the superior junction of the greater tuberosity and the humeral head articular surface, the mean number of loading cycles to the development of a 3-mm gap was 380 cycles (range, 272 to 549 cycles). This was a significantly greater number of cycles to failure than that seen with the repairs made with the standard 45° angle of anchor insertion (mean, 297 cycles; range, 171 to 408 cycles; $P < .0004$; Fig 3). Similarly, complete fixation failure occurred at a greater number of loading cycles with the

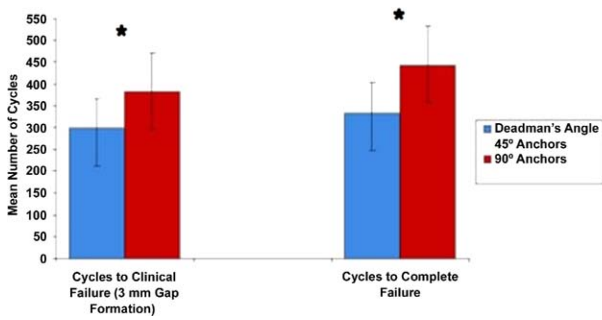

FIGURE 3. Mean cycles to clinical failure (3-mm gap formation) and complete failure at the tendon–suture interface. The asterisk indicates a statistically significant difference between the repairs made with the anchor inserted at 90° and those made with the anchor inserted at deadman's angle of 45°.

90° anchors (mean, 443 cycles) compared with the 45° deadman's angle suture anchors (mean, 334 cycles; $P < .0005$; Fig 3).

Post-testing examination of the suture anchors showed that 2 of the 28 (7%) rotator cuff repairs tested had gross anchor loosening present after cyclic loading. Both of these anchors were inserted at the deadman's angle of 45° and at the anterior position in the greater tuberosity.

DISCUSSION

In our cadaveric rotator cuff repair model, we found that repairs made with the screw-in suture anchor inserted at 90° to the superior junction of the greater tuberosity and the humeral head articular surface provided better soft tissue fixation stability than repairs made with the anchor inserted at the deadman's angle of 45°. This improvement in soft tissue fixation translated to a significant increase in the number of loading cycles required to achieve both clinical repair failure (3-mm gap formation) and complete loss of fixation within the supraspinatus tendon. In addition, although there were overall no instances of anchor pullout, in 2 specimens where the suture anchors were placed at a deadman's angle within the anterior aspect of the greater tuberosity, there was gross evidence of loosening after cyclic loading.

In a 1995 technical note, Burkhart[21] formulated the deadman theory of suture anchors by making an analogy to the anchoring effect of a corner wooden fence post by deadman wires. The function of the "deadman," or post, is to counteract the pull of the fence wire and therefore prevent the corner post from leaning. In Burkhart's analysis, the deadman was analogous to the suture anchor, the deadman wire was analogous to the suture, and the pull of the fence wire on the corner post was analogous to the pull of the rotator cuff. Using trigonometric calculations, Burkhart suggested that oblique placement of the suture anchor at an angle ≤45° to the surface of the bone increased the resistance to pullout, compared with anchor placement at 90°, by creating a force vector in the same plane as the pull of the rotator cuff. In addition, according to his calculations, oblique suture anchor placement created decreased tension in the suture, theoretically minimizing the chance of breakage.[21]

Burkhart et al.[22] followed the technical note with a cadaveric evaluation of the effect of cyclic loading on anchor-based rotator cuff repairs. The authors created 1- × 2-cm rotator cuff defects in 16 cadaveric shoulders and repaired each defect with 3 Mitek-RC suture anchors (Mitek; Westwood, MA), using simple sutures of No. 2 Ethibond. Cyclic loading of each specimen with 180 N, at a rate of 33 mm per second, resulted in 50% failure (defined as a 5-mm gap in the repaired defect) at a mean of 61 cycles and 100% failure (defined as a 10-mm gap in the repaired defect) at a mean of 285 cycles. In this study, the central suture always failed first and by the largest magnitude, indicating a situation of central tension overload. Only 1 specimen showed failure at the tendon–bone interface, with partial pullout of the suture anchor. The authors compared these results to data they compiled from a similar cyclic loading study evaluating repair with transosseous sutures and concluded that bone fixation with suture anchors was significantly less prone to failure than fixation obtained by bone tunnels.

Liporace et al.[1] used a cadaveric shoulder model to investigate the mechanical effects of suture anchor insertion angle for rotator cuff repair. The authors inserted Mitek SuperAnchors (Mitek) at angles of 90°, 75°, 45°, and 30° relative to the cortical border at the junction of the greater tuberosity and the articular surface, and loaded each specimen to failure. Mechanical failure occurred at the bone–anchor interface in all cases, and there was no statistically significant difference detected in the comparison of failure strength of the anchors at varying degrees of insertion angle. Of the 4 groups, anchors inserted at 75° showed the highest load to failure (219 N) and anchors inserted at 45° showed the lowest load to failure (169 N). Based on these findings, the authors concluded that the recommended suture anchor insertion angle of ≤45° should be reconsidered.

A clinical study by Cummins et al.[23] examined the mode of failure for rotator cuff tears managed with suture anchors identified at the time of revision surgery.[23] In a cohort of 342 patients, with rotator cuff tears treated by a single surgeon using suture anchors and a mattress-suturing configuration, 22 cases (6%) required revision surgery for failure of the index procedure. At the time of revision, 19 of the 22 shoulders showed failure at the tendon–suture interface, with the sutures cutting through the tendon. Of the remaining 3 cases, 2 patients developed new tears at sites away from the initial repair and 1 patient had failure at the tendon–bone interface, with pullout of the suture anchor. Based on these findings, the authors concluded that with the use of suture anchor fixation to bone, the weak link in rotator cuff repair is the tendon–suture interface.

Similar to the findings in the Cummins et al.[23] study, in our experimental model, every specimen failed in an identical manner, with the suture loop cutting through the supraspinatus tendon at the repair site. We believe that this mode of failure occurred secondary to the development of micromotion in the overall bone-anchor-suture-tendon construct, affecting fixation at the suture–tendon interface. With loading of the repaired rotator cuff tendon, there is an applied stress to the fixed eyelet of the screw-in suture anchor. For anchors inserted at an acute angle, windshield wiper–type motion can develop at the anchor–bone interface. This increases the amount of motion within the overall repair construct during each load, causing the suture loop to mechanically saw through the tendon with cycling. We found support for this theory after making sagittal cross-sections of the proximal humeri in 2 of our post-test specimens. In each of these specimens, anchors inserted at 90° had evidence of stable bony fixation after loading, with the diameter of the occupied space within the greater tuberosity being 5.00 mm and 5.03 mm, respectively. With each of these specimens, the size of the occupied space did not increase, compared with the thread diameter of the inserted anchor, indicating the absence of significant motion during cyclic loading. In contrast, in both specimens, the anchors inserted at the deadman's angle of 45° had evidence of windshield wiper–type motion, with an associated increase in the size of the occupied space within the greater tuberosity (7.15 and 8.16 mm, respectively; Fig 4). An additional potential mechanism of failure associated with anchor placement at the acute deadman's angle compared with 90° relates to the structure, properties, and strength of the tendons being repaired. In a study examining the role of graft materials in augmenting suture repair and reattachment of torn tendons, Kummer and Iesaka[28] showed that secondary to the structural isotropy of tendon, where strength between the tendon fibers is less than that of the tendons themselves, failure at the tendon–suture interface occurs along the tendon fibers rather than through it. An additional finding in this study was the fact that repaired tendons tend to have worse fixation strength when exposed to shear forces than pullout forces. It is possible that the applied force vector on the repaired tendon occurring with the anchor inserted at the deadman's angle of 45° has a greater component of shear force than that seen on the repair with the anchor inserted at 90°, leading to early fixation failure.

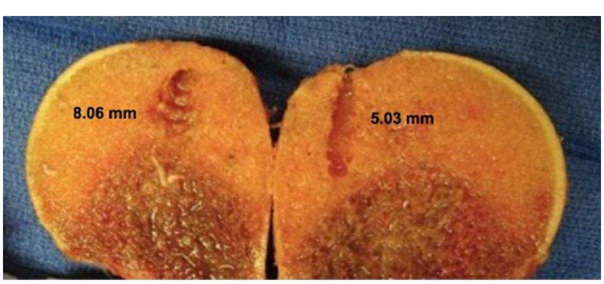

Figure 4. Sagittal cross section of a left proximal humerus post–cyclic loading. The space within the cancellous bone of the greater tuberosity occupied by the anchor inserted at deadman's angle was greater than that of the anchor inserted at 90°, indicating micromotion at the bone–anchor interface with loading.

Limitations of the current study include the use of cadaveric shoulder specimens and their inherent variability with respect to bone and soft tissue quality. In addition, secondary to specimen availability, those used in our study were slightly younger than the patients typically seen with rotator cuff pathology clinically. We attempted to limit the impact of specimen age and tissue variability on our results by creating a staggered, matched pair experimental set-up with respect to angle of anchor insertion and position within the greater tuberosity. In our rotator cuff repair model, we used a single suture anchor with its suture tied in a simple fashion to provide soft tissue fixation. Future studies investigating the effect of the angle of suture anchor insertion may use multiple suture anchors or mattress-type suture configurations in experimental repairs to better replicate current clinical scenarios.

CONCLUSIONS

Compared with anchors placed at the current standard of the deadman's angle of 45°, suture anchors placed at 90° to the junction of the greater tuberosity and the humeral head articular surface provided improved soft tissue fixation in an experimental rotator cuff model.

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