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# Biomechanical Performance of Bankart Repairs in a Human Cadaveric Shoulder Model

Khalid D. Mohammed,* MBChB, FRACS, David H. Sonnabend,* MBBS BSc (Med), FRACS, Jerome A. Goldberg,* MBBS, FRACS, Simon Hutabarat,* MBBS, Peter Walker,* MBBS, and William R. Walsh,*†‡ PhD

*From *Orthopaedic Research Laboratories, Orthopaedic Department, Prince of Wales Hospital and †Graduate School for Biomedical Engineering, University of New South Wales, Sydney, Australia*

## ABSTRACT

The objective of this study was to develop a method to evaluate the biomechanical performance of Bankart repairs in a human cadaveric shoulder in a clinically relevant orientation. Twenty fresh-frozen human cadaveric shoulder girdles were used to compare the biomechanical performance of intact anteroinferior capsulolabral complexes with the biomechanical performance of three Bankart lesion reconstruction techniques. Repairs were performed on surgically created Bankart lesions. Evaluations were performed with the shoulders in glenohumeral abduction and external rotation. The repair techniques employed interosseous sutures, Mitek GII suture anchors, or Acufex T-Fix devices. The suture material used in all repairs was No. 2 Ti-Cron. The biomechanical performance of the three reconstruction techniques did not differ, but each was significantly inferior compared with that of the intact shoulder samples. The interosseous repairs failed by suture pullout through soft tissue. Repairs in the Mitek GII group failed by pullout of the suture anchors, suture breakage, or pullout of the suture through soft tissue. Repairs in the T-Fix group failed by pullout of the suture through soft tissue or failure of the polymer portion of the T-Fix suture.

Traumatic avulsion of the anteroinferior capsulolabral complex of the shoulder from the anterior rim of the glenoid is commonly referred to as a Bankart lesion.[2] This pathologic lesion occurs in many cases of traumatic dislocation. Stabilization procedures focusing on surgical repair of the lesion have a high rate of clinical success.[1,7,8] However, open and arthroscopic repair of the Bankart lesion can be technically demanding. Many surgeons have sought new methods of reattachment to facilitate repair. Ease of use and accuracy are important, but adequate fixation strength is a prerequisite for any technique or device. Fixation strength influences rehabilitation programs and is important from the time of repair (time zero) until healing of the labrum to bone.

The pull-out strengths of several soft tissue devices ("suture anchors") have been examined in surrogate shoulder models[9] or in a cadaveric proximal tibia model.[4] These models however, do not accurately represent the clinical use of these devices. The purpose of this study was to develop a method of biomechanically testing Bankart lesion repairs in a human cadaveric shoulder model. Our intent was to develop a clinically relevant method that put mechanical load on the repair in the "at risk" position of abduction and external rotation, while excluding the effects of secondary restraints to anteroinferior dislocation. Bankart lesions repaired by three open reconstruction techniques—interosseous No. 2 sutures, Mitek GII suture anchors (Mitek Products, Ethicon Inc., a Johnson & Johnson company, Westwood, Massachusetts), and Acufex T-Fix sutures (Smith & Nephew Endoscopy, Andover, Massachusetts) were compared with the normal intact anteroinferior capsulolabral complex. The interosseous suture technique and Mitek GII suture anchors are currently used clinical for Bankart repairs, and the T-Fix suture has been used for rotator cuff reconstructions and meniscus repairs and may have a role in open Bankart procedures.

‡ Address correspondence and reprint requests to William R. Walsh, PhD, Orthopaedic Research Laboratories, Department of Traumatic and Orthopaedic Surgery, Prince of Wales Hospital - Edmund Blacket Building, Randwick, NSW 2031, Australia.
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## MATERIALS AND METHODS

Twenty unmatched fresh-frozen human cadaveric shoulders (from 11 men and 9 women) were used. Ages at the time of death ranged from 58 to 85 years (mean, 70.3). Specimens were separated into four groups of five shoulders: 1) intact capsule, 2) interosseous suture reconstruction, 3) Mitek GII suture anchor reconstruction, and 4) T-Fix suture reconstruction. Shoulders were thawed to room temperature for dissection. Leaving the capsule, supraspinatus tendon, and long head of the biceps brachii muscle intact, the shoulders were dissected free of soft tissues. A Bankart lesion was created using an open technique in groups 2 to 4 at the 3 o'clock to 6 o'clock positions in right shoulders and the 6 o'clock to 9 o'clock positions in left shoulders. A No. 15 scalpel blade was used to create each lesion by raising a periosteal flap along the anterior glenoid, detaching the insertion of the anteroinferior glenohumeral ligament from the glenoid. The Bankart lesions were repaired with three interosseous sutures, three Mitek GII suture anchors, or three T-Fix sutures (Fig. 1). The entry points on the anterior glenoid were standardized. Three standard surgeon's knots (No. 2 Ti-Cron) were used for all repairs.

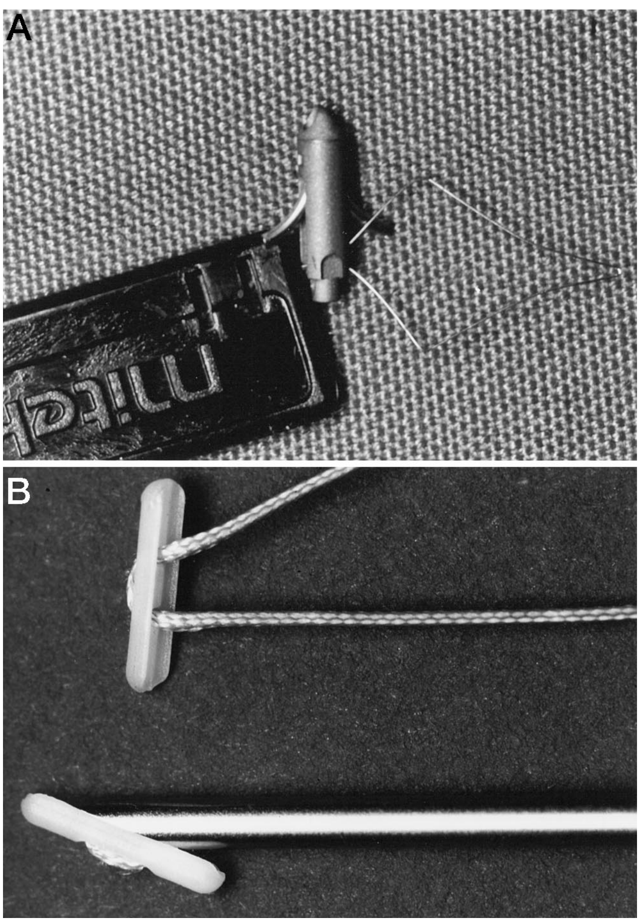


**Figure 1.** Mitek suture anchor (A) and T-Fix suture (B) used in this study

Before mechanical testing, the supraspinatus tendon, biceps tendon, and all capsule outside the zone of repair were sectioned midway between the glenoid and the humerus. The region of the capsule continuous with the repair, a rectangular strip including the anterior band of the inferior glenohumeral ligament, was left intact to eliminate variable load-sharing by soft tissues outside the Bankart repair zone. Shoulders in the intact-capsule group were prepared in an identical fashion but no Bankart lesion was created. The humerus was divided midshaft to allow the specimen to be loaded into the testing apparatus (Fig. 2). The acromion and the coracoid process were removed to ensure that the load could be applied directly to the humeral head, and that the humeral head could translate anteroinferiorly without obstruction. All shoulders were mounted in the testing apparatus in 80° of glenohumeral abduction and 90° of external rotation relative to the plane of the scapula. This position was chosen to simulate the at-risk position for anteroinferior instability as used clinically in the shoulder apprehension test. In vivo, this position equates to greater than 90° of shoulder abduction (glenohumeral and scapulothoracic abduction) and external rotation. The scapula was bolted to the apparatus. The humerus was held by a smooth pin through a predrilled hole. This pin was oriented perpendicular to the applied load, allowing the humeral head to displace anteriorly, while controlling the rotation of the humerus. Each specimen was visually checked in the apparatus before testing to ensure that the humeral head was congruent with the glenoid without any compression force between the two and that the Bankart lesion was directly opposite the applied load.

Mechanical testing was performed using an MTS 858 Mini Bionix testing machine (MTS Systems Corp., Minneapolis, Minnesota). The humeral head was translated anteriorly at 25 mm per minute. Mechanical load and deformation were recorded. Mode of failure and site of failure

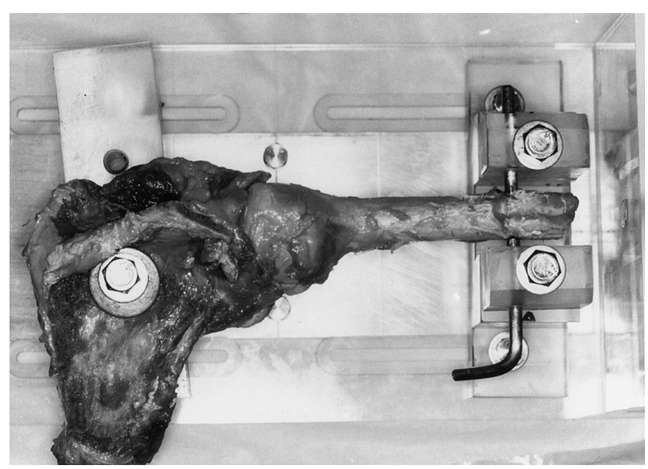

**Figure 2.** The testing apparatus, demonstrating the abducted and externally rotated humerus. The humerus is fixed with a smooth pin and allowed to freely rotate perpendicular to its long axis. The shoulder is fixed with a screw and a compression plate pushes on the humeral head anteriorly.

were noted in each specimen. Peak load, energy to peak load, and elongation of the anteroinferior capsulolabral complex were determined. Stiffness was calculated in the linear region of the load-deformation curve and in the initial portion of the curve at lower loads (between 30 and 50 N). Bone from the glenoid at the reconstruction site was harvested after testing for density using the Archimedes principle. A one-way analysis of variance followed by post hoc multiple comparison test (Duncan's multiple range procedure) was used to compare the three reconstruction techniques and the intact sample group using Statistica (Statsoft, Tulsa, Oklahoma).

## RESULTS

Mechanical testing of the reconstructions resulted in failure of the Bankart repairs in all cases. There were no statistically significant differences in the biomechanical data from the three reconstruction groups. The peak load, energy to peak load, and stiffness of the reconstructed groups were significantly different from the intact capsule group. The mean peak load to failure was 246.4 N (SD, 82.5) in the T-Fix group, 233.7 N (SD, 96.2) in the Mitek GII group, 261.7 N (SD, 76.6) in the interosseous-suture group, and 566.3 N (SD, 106.0) in the intact-capsule group. The mean (SD) for the energy at peak load, elongation at peak load, and stiffness are summarized in Table 1. No significant differences were found between the reconstruction techniques (groups 2 to 4). All reconstructions were significantly inferior for all mechanical parameters compared with the intact capsule ($P < 0.05$).

Mode of failure revealed some interesting differences between the groups. The intact capsules failed in a tearing fashion that propagated from the 3 o'clock to the 6 o'clock position in right shoulders and from the 6 o'clock to the 9 o'clock positions in the left shoulders. The interosseous-suture reconstructions failed by suture pullout through the soft tissues. The T-Fix group demonstrated two modes of failure: suture pullout through the soft tissues and failure of the T-Fix polymer adjacent to the suture loop. The Mitek GII group demonstrated three modes of failure: suture pullout through the soft tissues, Mitek GII anchor pullout, and suture breakage. The predominant mode of failure of the T-Fix group was suture pullout through the repair in one specimen, failure of the polymer in the region of the suture loop in one specimen, and both polymer failure and suture pullout through the repair in three specimens (Fig. 3). The predominant mode of failure in the Mitek GII group was pullout of the Mitek GII anchors in two specimens (Fig. 4), suture breakage in two cases (Fig. 5), and pullout of the suture through soft tissue in one case. There were no statistical differences between the glenoid bone densities of all four groups.

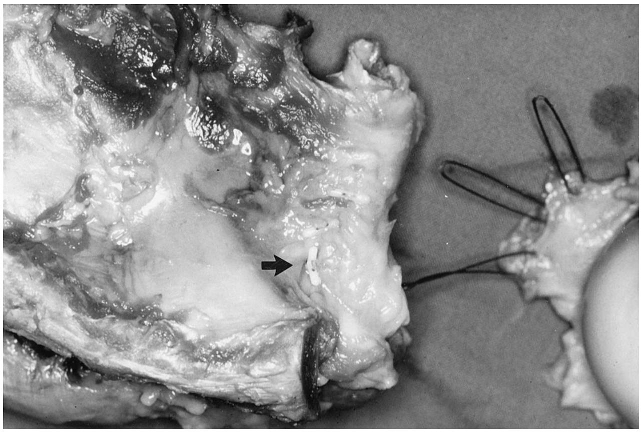

**Figure 3.** Failure of a T-Fix suture at the device-soft tissue interface (arrow). The polymer portion of the T-Fix remains on the external cortex on the glenoid.

## DISCUSSION

The present study reports an in vitro human cadaveric shoulder model to evaluate the biomechanical performance of isolated Bankart repairs immediately after reconstruction (time-zero). This testing model uses the clinically relevant orientation of abduction and external rotation to evaluate the repairs. The Bankart repair site was the only region we intended to examine. To eliminate the variable contributions of the secondary restraints, the soft tissues outside the repair zone were sectioned before mechanical testing. The anterior band of the inferior glenohumeral ligament has been noted not to be the only structure providing anteroinferior stability to the shoulder. Ferrari[5] has demonstrated the tension-sharing properties of the shoulder ligaments and capsule, and the altered tensions that occur with position. These tissues were not considered in our testing, thereby allowing direct evaluation of each fixation method. In addition, the humeral head and glenoid were not in contact during testing, thereby eliminating the concavity of the glenoid against the spherical humeral head as an additional resistance to anterior subluxation.

The ease of use of all three reconstruction techniques

TABLE 1
Biomechanical Data on the Intact Anteroinferior Capsulolabral Complex and on Bankart Lesions Repaired by Three Different Reconstruction Techniques[a]

| Reconstruction technique | Peak load (N) | Energy to peak load (N·mm) | Elongation at peak load (mm) | Stiffness between 30 and 50 N (N/mm) | Stiffness in the linear region (N/mm) |
|---|---|---|---|---|---|
| Intact capsule | 566.3 (106.0) | 5915.8 (1539.1) | 29.6 (2.6) | 11.6 (2.0) | 46.8 (5.4) |
| Interosseous sutures | 261.7 (76.6) | 2999.1 (1386.7) | 31.5 (1.9) | 5.8 (0.9) | 18.9 (5.0) |
| Mitek GII suture anchors | 233.7 (96.2) | 2618.7 (837.8) | 32.1 (3.8) | 5.4 (0.7) | 14.1 (7.6) |
| T-Fix sutures | 246.4 (82.5) | 2783.0 (496.5) | 26.5 (9.3) | 6.3 (2.6) | 14.5 (3.0) |

[a] Mean (SD).

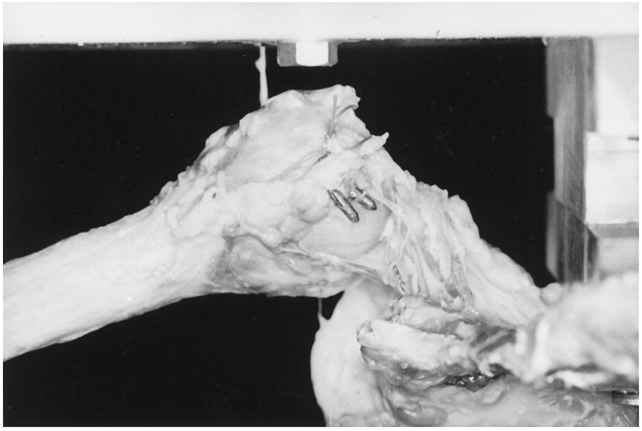

**Figure 4.** Failure of a Mitek GII suture anchor by anchor pullout.

**Figure 5.** Failure of a Mitek GII suture anchor by breakage of the eyelet of the device (arrow) and suture failure through the soft tissue.

was similar in the cadaveric shoulders in which a Bankart lesion had been created by open dissection. No significant differences in biomechanical performance of the interosseous sutures, T-Fix sutures, and Mitek GII suture anchors in the Bankart reconstructions were found. However, the reconstructed shoulders were significantly weaker than the intact control shoulders.

Stiffness values for Bankart reconstructions have not been reported in the literature. Stiffness was evaluated in two regions of the load-displacement curves: between 30 and 50 N, to represent the early loading, and later in the linear portion of the curve. The linear-region values for stiffness of the reconstructed shoulders did not differ between reconstruction groups and were significantly lower than those of the intact controls. The stiffness between 30 and 50 N revealed no significant difference between the reconstructions with the T-Fix sutures and the Mitek GII suture anchors compared with the intact capsule. However, the interosseous suture repair was less stiff than the other repairs at these loads. The greater amount of suture required through the bony tunnels may account for, in part, the lower stiffness values. These data highlight that the mechanical load per unit deformation of the reconstructions after repair of Bankart lesions does not recreate the normal tissue properties.

The values reported here for reconstructions of Bankart lesions are slightly greater than those found in the literature in studies using human shoulder models. The maximum load to failure in the reconstructed shoulders in our study was 261.7 N using an interosseous suture (No. 2 Ti-Cron). Samples were tested in abduction and external rotation and a displacement of 25 mm/min. Shall and Cawley[9] used a human glenoid and surrogate humeral head model repaired with two suture anchors with No. 0 braided polyethylene. The testing orientation was reported with the alignment of the glenoid and humeral head surrogate such that the vector of the repaired tissue approximated that of the in vivo condition and an anterior subluxation of the humeral head surrogate at a rate of 31.75 mm/sec. They reported a maximum load to failure of 217.32 N. Hecker et al.,[6] using a human shoulder model with three suture anchors and No. 1 Dacron suture, evaluated their Bankart repairs by pulling on the soft tissue approximately perpendicular to the sagittal plane and parallel to the coronal plane at 60 mm/min. They report a mean load to failure of 191 N. Direct comparisons between studies is clearly difficult because the differences in testing orientation, number of devices used, and suture size will influence the overall biomechanical performance of the reconstructions.

The mode of failure showed an interesting difference between the T-Fix and Mitek GII devices. Failure of the T-Fix suture through the soft tissues or failure of the polymer device was observed in the T-Fix group. Mitek GII samples failed by either device pullout, suture failure, or soft tissue failure. Hecker et al.[6] and Shall and Cawley[9] report similar failure modes in their models. The cancellous bone stock of the glenoid appears to be an important feature in Mitek GII suture anchor failure because the suture anchor is embedded in the bone for fixation. The T-Fix suture, on the other hand, is a transglenoid device that relies on the quality of the posterior glenoid cortical bone rather than on the quality of the glenoid cancellous bone. The T-Fix may confer some advantage in patients with poor quality or limited amount of glenoid cancellous bone, such as in the elderly and in some cases of revision stabilization. The transglenoid nature of the T-Fix fixation removes the possibility of debris in the glenohumeral joint if the fixation fails because of reinjury.

A standard surgeon's knot with No. 2 Ti-Cron suture was used in our repairs. Suture failure was observed in at least one Mitek GII device in four of the five reconstructions. No Ti-Cron suture failures were observed in the T-Fix samples. Differences in the suture properties may play an important role in the biomechanical performance of the reconstructions and should be considered when evaluating the reconstruction device and its performance. The testing orientation may also play a role in the suture failure through a stress concentration caused by the direction of the loading.

There are limitations with in vitro models to evaluate the biomechanical performance of Bankart repairs. These limitations include the type of tissue used (animal or human), location of the lesion, age of the donor, and testing conditions (orientation and speed). Shea et al.,[10] using a canine model, did not localize lesions to the anteroinferior capsule, where they most commonly occur, or report the orientation of testing. Glenohumeral abduction and external rotation results in tension in the inferior glenohumeral ligament and related capsule and more closely represents the loading conditions in vivo than a uniaxial test. Hecker et al.[6] and Shall and Cawley[9] used human cadaveric shoulder models to examine Bankart repairs. In both studies the humerus was detached and a surrogate humeral head was used in testing. In the Hecker et al. study, the repair was tested by pulling on the capsule with the surrogate humeral head, and in the Shall and Cawley study, the repair was tested by pushing on the capsule using the surrogate humeral head. Neither study oriented the capsule into abduction and external rotation.

A human proximal tibia model was reported by Carpenter et al.[4] to characterize and compare the biomechanical performance of a number of suture anchors secured with a suture loop with the force applied parallel or perpendicular to the fixation device at 60 mm/min. The human tibia provided a reproducible testing site for a comparison of the device fixations, which were found to depend on the direction of the applied force and quantity of bone. Such models do not consider a soft tissue component or take into account anatomy and orientation of the glenohumeral joint, which may play a role in the overall fixation.

Barber et al.[3] reported the mechanical properties of a number of suture anchors using a fresh porcine femur model to compare the relative size, design (screw or nonscrew), and composition (metal or nonmetal). Samples were tested at 750 mm/min under uniaxial loading parallel to the insertion site. The ultimate and mean failure strengths of each anchor and mode of failure were reported. This comprehensive study highlights the importance of drill hole size in cancellous bone. This report, however, did not intend to specifically examine soft tissue fixation of Bankart lesions with the loading orientation that occurs in vivo.

Our study shares some deficiencies with those of the studies of Hecker et al.[6] and Shall and Cawley.[9] Our cadavers were older than the age group in which Bankart lesions are most common (although the ages of the cadavers were not stated in the Shall and Cawley study). The Bankart lesions were created by dissection, not as a result of shoulder dislocation. Therefore, possible capsular stretching and adaptive changes that may occur in vivo have not been considered. The testing speed is standardized in each study to allow valid comparisons, but it does not reflect the multidirectional forces that a Bankart repair is subjected to in vivo. No study has yet examined a cyclical loading and subsequent failure, which may affect the way healing occurs. Finally, all cadaveric studies examine the fixation properties immediately after the reconstructions and do not take into account tissue healing. These studies, however, do provide information on the initial strength of the repairs and on the performance of the devices used for reconstruction, which helps in formulating postoperative movement regimes.

In summary, we developed a human cadaveric shoulder model to test the biomechanical performance of isolated Bankart repairs oriented in abduction and external rotation that can be used to test other techniques in the future. The present study reveals that the biomechanical performance of repairs using interosseous sutures, Mitek GII suture anchors, and T-Fix sutures fails to reproduce the properties of the natural intact tissue. Care must be taken when comparing the performance of different reconstruction methods as a number of factors play a role in their overall biomechanical performance.

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