Shoulder Anteroinferior Glenoid Labrum Reconstruction With the Long Head of the Biceps Tendon Restores Glenohumeral Stability: A Cadaveric Biomechanical Study

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Purpose: The purpose of this cadaveric study was to determine feasibility and assess biomechanical stability of glenoid labral reconstruction utilizing the long head of the biceps tendon (LHBT) as a local autograft for labral deficient shoulders. **Methods:** Ten cadaveric shoulders underwent resection of all soft tissue structures except the labrum and LHBT. The scapula and humerus were separately attached to a custom shoulder testing apparatus allowing for 22.5 N of compressive isotonic force across the joint. An Instron (Electroplus 1000) measured the peak force (N) as the humeral head was translated over the anteroinferior glenoid rim through 10 cycles. Shoulders were tested in 3 separate scenarios: intact labrum, resected labrum from 3- to 6-o'clock (for a right shoulder), and labral reconstruction with the LHBT. Reconstruction was performed by performing LHBT tenotomy at the level of the pectoralis major insertion. The proximal LHBT tendon, left attached to the supraglenoid tubercle, was then attached to the anteroinferior glenoid rim with suture anchors. **Results:** Mean (SD) length of the LHBT was 76.1 (12.9 mm) and the diameter was 5.9 (1.6) mm. Peak force for intact labrum was significantly greater than the deficient labrum state (14.06 vs 11.78 N; $P = .012$). Peak force for labral reconstruction (16.67 N) was significantly greater than both intact and deficient labral states ($P < .001$ and $P = .011$, respectively). In all specimens, the length for the LHBT to the pectoralis major insertion was sufficient for reconstruction of the labrum to the 6-o'clock position. **Conclusions:** Glenoid labrum reconstruction with the LHBT is a feasible option to restore glenohumeral stability, with peak force to displacement significantly greater than the labral-intact and labral-deficient states. **Clinical Relevance:** This reconstruction may be an option for augmentation in the labral-deficient shoulder.

Ideal treatment of shoulder instability continues to evolve. Previous studies have determined the importance of compressive forces centering the humerus within the concavity of the glenoid, thus providing stability to the shoulder.[1,2] This is especially important with the knowledge that capsular structures are not under tension during midranges of motion and shoulder stability within the extremes of motion is independent of capsular constraint.[3] An important structure in creating the glenoid cavity is the labrum, which constitutes 50% of the glenoid depth.[4] Demonstrating the importance of the labrum to the stability of the shoulder, Lazarus et al.[5] showed that creation of a chondral-labral defect from 3-o'clock to 6-o'clock (on a right shoulder) resulted in a 65% reduction in the stability ratio. When considering repair options, research has shown that even in the cadaveric setting with artificially created Bankart lesions, only horizontal mattress sutures have the ability to restore labral height, while simple sutures result in loss of height.[6] Thus, even in the ideal situation without scarring and/or loss of tissue, ability to restore labral height may be diminished.

Clinically, recent work is helping to understand the correlation of decreased labral height/size to

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postoperative instability and diminished patient-reported outcomes.[7-9] Despite this, to our knowledge, there are very few described options to reconstruct the glenoid labrum. The purpose of this cadaveric study was to determine feasibility and assess biomechanical stability of glenoid labral reconstruction utilizing the longhead of the biceps tendon (LHBT) as a local autograft for labral-deficient shoulders. We hypothesized that stability following reconstruction of the glenoid labrum with the LHBT would restore peak force to dislocation with significant improvement to the Bankart lesioned state.

Methods

This was an in vitro biomechanical study using cadaveric shoulders to test the feasibility and biomechanical glenohumeral stability when the LHBT is used as a reconstructive graft in a labral-deficient shoulder. For this study, 12 cadaveric shoulders were utilized. Funding was provided by the James E. Ireland Foundation for purchase of shoulders and testing materials. Suture anchors were provided by Smith and Nephew, Andover, MA. Shoulders were inspected by an orthopaedic surgery resident (A.J.Z.) during initial dissections and confirmed again by A.J.Z. and by the senior author (S.K.), a fellowship-trained shoulder and elbow surgeon, at the time of testing for any preexisting labral, chondral, or biceps pathology. Two shoulders were excluded due to the presence of such pathology, 1 shoulder for chondral wear and another excluded for absence of an LHBT, leaving 10 for final analysis The mean age of the 10 shoulders in the study was 77.2 years; 2 were male and 8 were female. Six right shoulders and 4 left shoulders were included.

Shoulders were prepared by removing all soft tissue except the labrum and the LHBT. Prior to removal of the pectoralis insertion, the level of the distal pectoralis tendon was marked on the LHBT with a 6-0 Prolene suture (Ethicon). A digital picture of the biceps tendon was taken with a ruler immediately adjacent to the tendon for scaling. ImageJ software (National Institutes of Health) was used to measure distance from LHBT insertion on the supraglenoid tubercle to the marked suture, indicating length of the LHBT to the proximal pectoralis major insertion.

The humerus was cut just distal to the deltoid tuberosity in the axial plane while the scapular body was cut medial to the coracoid in the sagittal plane. The humeral shaft and scapular body were potted in separate polyvinyl chloride (PVC) containers using Bondo All-Purpose Putty (3M) as the grouting material. Two additional crossed Steinmann pins were utilized to affix the scapula to the PVC container to provide additional stability. The potted humerus and glenoid were then inserted and secured to a custom-made shoulder testing apparatus (A K Kraussel Tool & Manufacturing Corporation) (Fig 1). The humerus was positioned in 60 degrees of abduction to the surface of the glenoid, measured with a goniometer. This amount of abduction was selected to simulate 90 degrees of total shoulder abduction.[10,11] Rotation of the humerus was set at 60 degrees of external rotation, with 90 degrees of external rotation defined as the bicipital groove facing directly superior.[10,12,13] In accordance with previous studies, 22.5 N of glenohumeral joint force was created using a custom pulley system attached to a mounting frame that was placed on sliders.[10] The glenoid was orientated such that the axis of a line between 10:30 and 4:30 (for a right shoulder) is directly vertical. Please note for simplicity of description, left shoulder clock face orientation has been flipped to right shoulder orientation. A spirit level was utilized to align the glenoid face perpendicular to the horizontal axis. Normal saline was utilized to keep shoulders from drying out on the day of testing, as well as applied between each testing scenario.

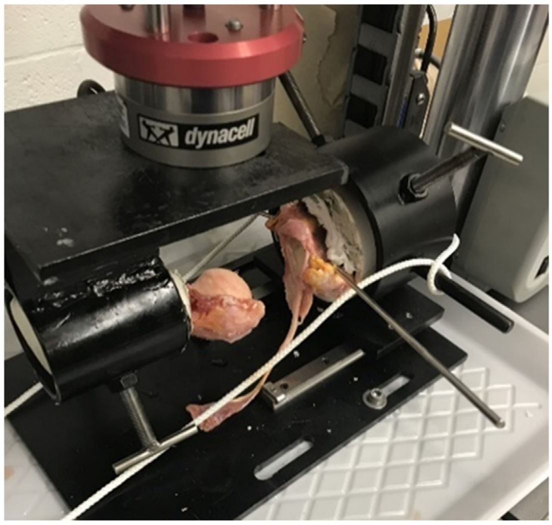

Fig 1. Testing apparatus. The humerus is mounted to the Instron Electroplus 1000, which provides a force to translate the humeral head over the glenoid. The glenoid is mounted to a low-friction sliding platform with a pulley system providing 22.5 N of joint compression force.

An Instron Electroplus 1000 was utilized to measure force based on amount of displacement. Utilizing the excluded cadaveric shoulders to conduct trail tests, it was determined peak force was obtained by 3 mm of displacement from the center of the glenoid, and thus 5 mm of displacement was utilized to avoid overt dislocation and unnecessary tissue damage. Each scenario underwent 10 cycles at 1 Hz. The following 3 testing scenarios were tested:

1. The native intact shoulder, with a normal labrum
2. A Bankart lesion was created by removal of the labrum from 3- to 6-o’clock (for a right shoulder).
3. The labrum was then reconstructed using the LHBT, with retained attachment to superior glenoid, in the

Fig 2. Labral reconstruction in a right shoulder. Glenoid labral reconstruction with retention of the supraglenoid tubercle insertion site. In this specimen, an additional 1:30 suture anchor was utilized to prevent bowstringing between the insertion site and the 3:00 anchor.

absence of the native labrum at the 3- to 6-o'clock site.

The reconstruction technique was performed by placing a retaining attachment of the LHBT to its origin on the supraglenoid tubercle. The tendon was then wrapped anteriorly and secured using 1.6-mm Suture Fix anchors (Smith & Nephew). Suture anchors were placed at 3:00, 4:30, and 5:30 (right shoulder). An additional anchor was placed at 1:30 if the LHBT was found to bowstring from its insertion to the first anchor at 3-o'clock. Knots were tied with 3 half-hitches in the identical direction followed by 3 half-hitches with reversing alternating posts (Fig 2). All labral reconstructions were performed by the senior author (S.K.).

Statistical Analysis

Mean LHBT distance and diameter were calculated in Microsoft Excel (Microsoft, Inc). A repeated-measures analysis of variance was used to compare the 3 states of the labrum with Bonferroni post hoc analysis for pairwise comparisons. An α level of $P < .05$ was considered statistically significant, and all analyses were performed using SPSS Statistics (version 24; IBM).

Results

Mean (SD) diameter of the LHBT was 5.9 (1.6) mm with a mean (SD) length of 76.1 (12.9) mm from the supraglenoid tubercle to the proximal edge of the pectoralis major insertion.

The mean peak force was 14.06 N (95% confidence interval [CI], 10.31-17.81) in the intact state, 11.78 N (95% CI, 8.46-15.10) after resection of the labrum, and 16.67 N (95% CI, 12.35-20.99) after reconstruction the labrum with the LHBT (Fig 3). The peak force to displacement in the labral resected state was found to be significantly less than both the intact ($P = .012$) and reconstructed states ($P = .011$). Additionally, peak force to displacement following labral reconstruction was significantly greater than the labral-intact state ($P < .001$). Overall, there was a 41.5% increase in the peak force to displacement from the labral-deficient to the labral-reconstructed state and 18.6% greater than the labral-intact state. No statistically significant correlation was found between diameter of the LHBT and peak force ($r = -0.38$, $P = .28$).

Discussion

The most important findings of this study were the restoration of peak force to displacement and feasibility of glenoid labral reconstruction with the LHBT. Following reconstruction, peak force to displacement was 41.5% and 18.6% greater than the labral-deficient and labral-intact state, respectively.

Despite advances in arthroscopic technology and techniques, high rates of recurrent shoulder instability continue to be reported in the literature.[14-18] A recent study assessing long-term follow-up of a US population showed recurrent instability of nonoperatively managed patients ≤15 years of age and 16 to 20 years of age to be 38.1% and 47.1%, respectively. Even with surgery, patients between ages 16 and 20 years had a recurrence rate of 24.8%.[17] Recurrent instability has been shown to be higher in those who underwent arthroscopic Bankart repair after at least 2 events compared with a single dislocation event.[19] In the study by Marshall et al.,[19] the recurrent group was found to have postoperative instability of 29% vs 62% ($P < .001$), respectively, despite no reported differences in demographic variables, including the presence of glenoid or humeral head bone loss. Additionally, in those that do recur after a stabilization surgery, revision arthroscopy has been shown to have recurrent instability as high as 42%,[20] whereas utilization of bone graft techniques for recurrent instability has shown higher complication rates than arthroscopic options.[21]

Previous studies have demonstrated the importance of the glenoid labrum for shoulder stability. An early concavity-compression model by Lippitt et al.[1] demonstrated a linear relationship with effective

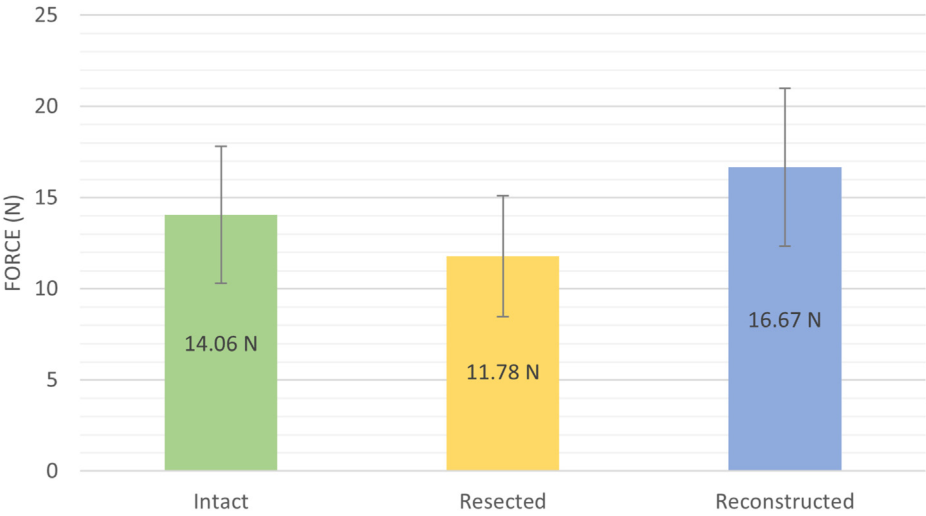

Fig 3. Peak force of displacement in each testing state. Average peak force of each testing state. Error bars denote 95% confidence intervals of each testing state.

depth of the glenoid and the stability ratio. In their work, labral excision decreased the effective depth of the glenoid and continued to show a linear relationship with stability. In addition to creating a bumper to displacement, the labrum has also been shown to work via a piston-and-valve model with negative intra-articular pressure creating passive stability to the shoulder joint.[22] Given these important properties of the labrum, the current study sought to devise and evaluate a potential solution to re-creating anatomy in a labral-deficient shoulder.

Recently, augmentation of the labral repair with LHBT transfer, through a subscapularis split, to the inferior glenoid was assessed in a cadaveric model by Lobao et al.[11] In this study, authors demonstrated that Bankart repair alone did not restore load to dislocation compared to the intact state. However, augmentation with LHBT transfer was able to achieve load to dislocation that was statistically significantly higher than Bankart repair and without a statistical difference from the intact state.[23] This study differs, as no comparison to labral repair was made since the goal was to develop a technique for situations in which adequate labral tissue is not present. However, this study did show labral construction significantly increased peak force to displacement compared to even the labral-intact state. The current study was designed to assess stability afforded by the reconstructed labrum with the shoulder dissected down to its simplest form. Given the immense range of motion of the shoulder, the glenohumeral ligaments do not become taught until extreme ranges of motion.[1,24] In performing labral reconstruction, capsular plication is often undertaken, which could confound experimental results. This study sought to evaluate the role of labral reconstruction in isolation, and thus the potential for the confounding effect of plicating the capsule done at the time of labral reconstruction was eliminated from the study design. Additionally, bone loss was not included in the current study scenarios, and future studies would elucidate this effect on stability with labral reconstruction.

Limitations

With any biomechanical cadaveric study, inherent limitations are present. An a priori power analysis was not performed as there were no published data or pilot data available prior to the current study that could have been used to inform the analysis. The time zero nature does not consider healing and adaptation of living tissue as well as the frequent chondral injuries that often coexist. The advanced age of the specimens may have also compromised tissue quality. Despite exclusion of shoulders with significant articular and biceps pathology, instability typically occurs in younger patients with perhaps differences in labral size and quality. Additionally, dynamic rotation of the humerus was not utilized in dislocation, whereas the humerus was placed in a static position of abduction and external rotation and then translated in a linear vector over the face of the glenoid.[2,5,10,13] Soft tissue attachments, including the capsule and rotator cuff tendons, were removed for this study, and the stabilizing contributions of these structures were not replicated beyond creation of joint compressive force. The shoulders in this study were also not fully dislocated, and instead, a force-displacement hysteresis curve was utilized to identify the peak force. This was conducted to limit excessive damage to the shoulders and the stability to which they were fixated in the testing apparatus. Labral repair was also not assessed in this study as a comparison to labral reconstruction. It was felt the addition of this testing scenario would create excessive glenoid damage. The nature of the study prevented randomization in the treatment sequence; however, all specimens and treatment scenarios were tested under the same configuration and loading.

Conclusions

Glenoid labrum reconstruction with the LHBT is a feasible option to restore glenohumeral stability, with peak force to displacement significantly greater than the labral-intact and labral-deficient states.

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