Original Article

Acellular Human Dermal Allograft Tuberoplasty Improved the Biomechanics in Mid-Range and Higher Abduction Angles in a Cadaveric Model of Massive Irreparable Rotator Cuff Tears

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Purpose: To evaluate the biomechanical effects of acellular human dermal allograft tuberoplasty (AHDAT) in a cadaveric model of an irreparable supraspinatus + anterior one-half infraspinatus (stage III) rotator cuff tear. **Methods:** Eight cadaveric shoulders were tested at 20°, 40°, and 60° of glenohumeral abduction (AB) and 0°, 30°, 60°, and 90° of external rotation (ER). Superior humeral translation, acromiohumeral distance, and subacromial contact were quantified for 4 conditions: (1) intact, (2) stage III tear (entire supraspinatus and anterior one-half infraspinatus), (3) single-layer AHDAT, and (4) double-layer AHDAT. **Results:** Stage III tear significantly increased superior translation at 20° and 40° AB and all ER angles and at 60° AB/60° ER ($P \leq .045$ vs intact). Compared to the stage III tear, the single-layer AHDAT significantly decreased superior translation at 60° AB/60° ER ($P = .003$), whereas the double-layer AHDAT significantly decreased superior translation at 40° and 60° AB at all ER angles except 60° AB/0° ER ($P \leq .028$). The stage III tear significantly decreased acromiohumeral distance at 20° AB ($P \leq .003$); both grafts increased acromiohumeral distance to intact levels ($P \geq .055$ vs intact). Stage III tear increased subacromial contact pressure at 20° and 40° AB/0° and 30° ER and at 60° AB/30° and 60° ER ($P \leq .034$). Both AHDAT groups decreased contact pressure at 40° AB/30° and 60° ER back to intact, whereas the double-layer AHDAT also decreased contact pressure at 20° AB/0° and 60° ER and 60° AB/30° ER ($P \geq .051$ vs intact). **Conclusions:** Both single- and double-layer grafts for AHDAT improved superior translation, subacromial contact characteristics, and acromiohumeral distance after a stage III rotator cuff tear, with varying effectiveness due to the position-dependent nature of greater tuberosity to acromial contact with abduction. **Clinical Relevance:** The best treatment for massive or irreparable rotator cuff tears is a matter of concern. The results of this study will help determine whether an acellular human dermal allograft tuberoplasty is a potential treatment option worthy of further investigation.

Irreparable rotator cuff tear characteristics include tendon retraction with inelasticity,[1-3] muscle atrophy,[1-6] and fatty infiltration.[1-7] For such tears, treatment options include partial repair,[8] bursal acromial reconstruction,[9] tendon transfers,[10-12] acellular human dermal allografts as a bridging procedure,[10,13-18] superior capsule reconstruction (SCR),[10,19,20] anterior cable reconstruction (ACR),[21,22] and biologic tuberoplasty.[10,23]

The rotator cuff provides static and dynamic glenohumeral joint stability, and tears of sufficient size can result in superior instability and subacromial impingement, causing pain and impaired activities of daily living.[1,24,25] In addition to bone-on-bone contact between both the humeral head and greater tuberosity against the acromion, irreparable tears alter the kinematics in the shoulder joint, which can lead to degenerative conditions such as osteoarthritis and cuff tear

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Received July 10, 2023; accepted December 14, 2023.

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2666-061X/23946
https://doi.org/10.1016/j.asmr.2023.100868

arthropathy. SCR and ACR have demonstrated restoration of superiorly directed stability of the shoulder joint without substantial range of motion loss.[1,20-22] Although the SCR procedure was initially performed with tensor fascia lata (TFL) autograft, surgeons in the United States have predominantly utilized acellular human dermal allografts.[1,26] Acellular human dermal allografts provide graft uniformity and decrease donor site morbidity that occurs while harvesting the TFL from the patient.[26] Patients maintaining residual tuberosity coverage with dermal allograft after a failed SCR procedure were in a cohort of persistent pain relief.[10,13,14,19]

The purpose of this study was to evaluate the biomechanical effects of acellular human dermal allograft tuberoplasty (AHDAT) in a cadaveric model of an irreparable supraspinatus + anterior one-half infraspinatus (stage III[27]) rotator cuff tear. We hypothesized that AHDAT in stage III rotator cuff tear conditions will improve biomechanical characteristics compared to the defect condition and the single-layer AHDAT would biomechanically perform in a similar manner as the double-layer AHDAT.

Methods

Specimen Preparation and Setup

Eight fresh-frozen cadaveric shoulders (3 male, 5 female) with a mean age of 67.1 ± 8.7 years were used for this biomechanical evaluation. The specimens were tested using a custom shoulder testing system that permits 6 degree-of-freedom of shoulder positioning and muscle loading[1,21,26] (Fig 1). Institutional review board approval was waived by our institution for this basic science cadaveric study. All specimens were assessed by a fellowship-trained shoulder surgeon (M.P.) before testing. The shoulders were macroscopically intact with no arthritis or rotator cuff tears. The tendinous insertions of the supraspinatus, infraspinatus, teres minor, subscapularis, pectoralis major, latissimus dorsi, and deltoid (anterior, middle, and posterior) were preserved, in addition to the shoulder capsule and the coracoacromial ligament. All remaining skin, subcutaneous tissue, and muscles were removed from each specimen. The humerus was transected 2 cm distal to the deltoid tuberosity.

Suture loops were placed into the tendinous insertions of each muscle for loading. For kinematic, translation, and acromiohumeral distance measurements, small screws (#4 × ¼ in.; Philips Screw Company), used as markers for the MicroScribe, were placed on the coracoid, the lateral scapular spine, and the medial scapular spine. In addition, 3 small screws were placed proximally, distally, and posteriorly on the humeral shaft approximately 1 cm apart from each other. A 3-dimensional digitizer (MicroScribe 3DLX; Revware) was used to digitize the position of the humerus relative to the scapula at all positions with both balanced muscle loading and a superiorly directed, unbalanced muscle-loading condition.

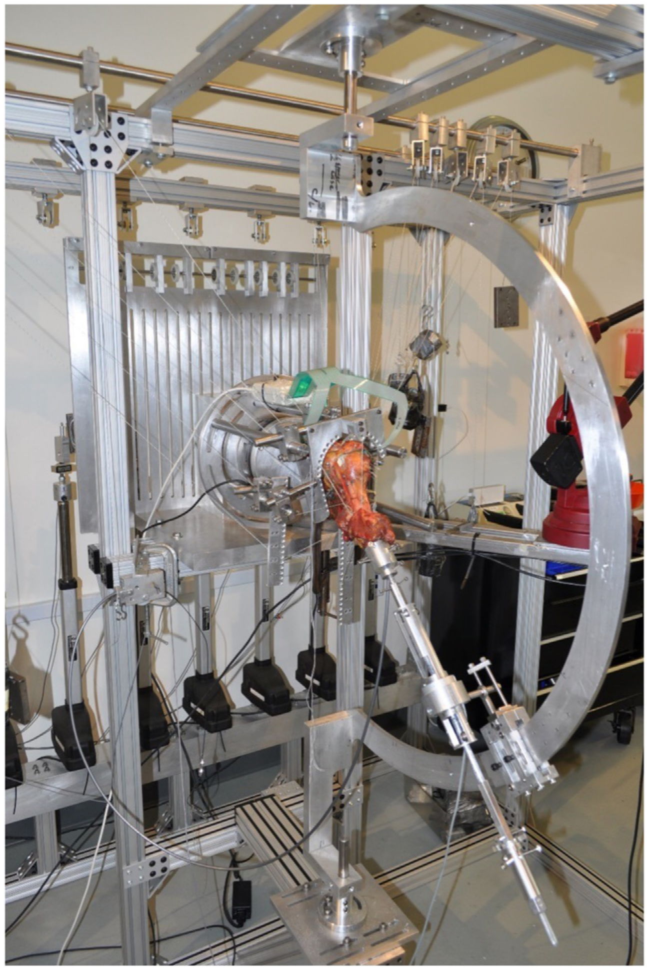

Fig 1. A left cadaveric shoulder mounted on the custom shoulder testing system at 40° of abduction.

The scapula was fixed to a custom metal plate using 3 large bolts. The humerus was attached to a linear bearing system using intramedullary rod fixation. The scapula was mounted and positioned at 20° of anterior tilt in the scapular plane to mimic anatomic position, and the humeral rod was attached to an arc located on the custom testing system. Throughout the experiment, the specimens were kept moist with 0.9% saline.

An adjustable cable-pulley system was used to simulate muscle forces selected based on the muscle's physiologic cross-sectional area ratios and force couple balance.[1,21,26,28,29] No. 2 FiberWire (Arthrex) was used to attach the sutured tendons to the corresponding muscle load on the pulley system. Two loading conditions were tested utilizing the force couple concept: balanced and unbalanced loading conditions.[1,21,26,28,29] For the balanced load, the following muscle forces were used: deltoid, 40 N; latissimus dorsi, 20 N; pectoralis major, 20 N; subscapularis, 10 N; supraspinatus, 10 N (only in the intact condition); infraspinatus, 5 N (only in the intact condition, 2.5 N for remaining conditions); and teres minor, 5 N. For the unbalanced, superiorly directed load, the following muscle forces were used: deltoid, 80 N; subscapularis, 10 N; supraspinatus, 10 N (only in the intact condition); infraspinatus, 5 N (only in the intact condition, 2.5 N for remaining conditions); and teres minor, 5 N. The unbalanced loading condition was used to provide a superior directed load, compared to the balanced loading condition, to elevate the humeral head for measurements of superior translation and subacromial contact pressure.

Testing Conditions

Four conditions were tested: intact, stage III rotator cuff tear, single-layer AHDAT, and double-layer AHDAT. The first condition tested was the shoulder with an intact rotator cuff. After all the measurements were obtained from the intact condition, a stage III[27] rotator cuff tear (entire supraspinatus and anterior one-half infraspinatus) was created for the second condition. To simulate the stage III tear, the supraspinatus was first entirely dissected from its insertion on the greater tuberosity. Once the supraspinatus was completely removed, the anterior half of the infraspinatus was dissected off its insertion on the greater tuberosity and measurements were obtained. The entire supraspinatus and anterior infraspinatus were then transected completely to the glenoid.

To prepare the greater tuberosity for the single- and double-layer AHDAT, a burr was used to debride the greater tuberosity of tendon and to create a smooth surface for the allograft to cover. For the third condition, a single-layer dermal allograft was positioned with the medial border of the graft flush with the articular margin of the humerus and the lateral border of the graft fixed over the greater tuberosity. After testing the third condition, the single-layer graft was removed and double-layer AHDAT was performed for the fourth condition. The mechanical integrity of the proximal humerus was not disrupted while testing, and thus, the same specimen was used for all 4 conditions.

Graft Preparation and Fixation

To determine the dimensions of the graft, a MicroScribe was used to measure the anterior-posterior and medial-lateral dimensions of the tuberosity where the supraspinatus and anterior one-half infraspinatus were originally attached. The Acellular Human Dermal Allograft (3-mm-thick ArthoFLEX; LifeNet Health) was then sized to match the medial-lateral distance and 15% smaller in the anterior-posterior direction to ensure graft tension over the defect.[30] To create the double-layer graft, the anterior-posterior length of the single-layer graft was used and the medial-lateral width of the single-layer graft was doubled. The graft was then folded in half and secured with a suture located on the lateral border of the graft. Prior to graft fixation onto the greater tuberosity, a Scorpion suture passer (Arthrex) was used to pass a 1.3-mm TigerLink SutureTape (Arthrex) through each corner of the graft. The graft thicknesses of both the single-layer and double-layer prepared grafts were measured pre- and post-testing using an area micrometer.

On the medial side of the greater tuberosity, a punch was used to create 2 anchor sites for the double-loaded 4.75-mm Corkscrew FT Suture Anchor (Arthrex) at the articular margin (Fig 2A). The medial side of the graft was shuttled onto the greater tuberosity, and 5 simple knots were used to secure the medial border of the graft to the humerus. The graft was stretched over the greater tuberosity to determine its lateral border fixation points (Fig 2B). The procedure of fixing the lateral border of the graft to the humerus was the same as the medial border procedure. After the single-layer augmentation was tested and removed from the greater tuberosity (Fig 2C), the same process was used to fixate the double-layer graft on the tuberosity (Fig 2D).

Measurements

Biomechanical testing was performed at 20°, 40°, and 60° of glenohumeral abduction, which corresponds to 30°, 60°, and 90° of shoulder abduction.[31,32] At each abduction, angle measurements were made at 0°, 30°, 60°, and 90° of external rotation. Prior to measurement, specimens were preconditioned with 5 cycles at 2.2 Nm of torque in external and internal rotation. First, the humeral head position relative to the scapula was recorded for the balanced loading condition at a given abduction angle; the loading was then changed to the unbalanced loading condition, and the humeral head position and the subacromial contact pressure measurements were performed. Following all measurements at 1 abduction angle, the balanced loading condition was reapplied and the specimen was moved to the next abduction angle, where these measurements were repeated.

The difference between the distance of the digitized points of the lateral scapular spine and the proximal humerus of the balanced and unbalanced loading conditions was defined as the glenohumeral superior translation of the humerus at 20°, 40°, and 60° of glenohumeral abduction.

Contact area, contact force, peak pressure, and contact pressure were measured only during the unbalanced muscle-loading condition.[1,21,26] A Tekscan pressure-measuring system (Model 4000; saturation pressure 10.3 MPa; Tekscan) was inserted in the

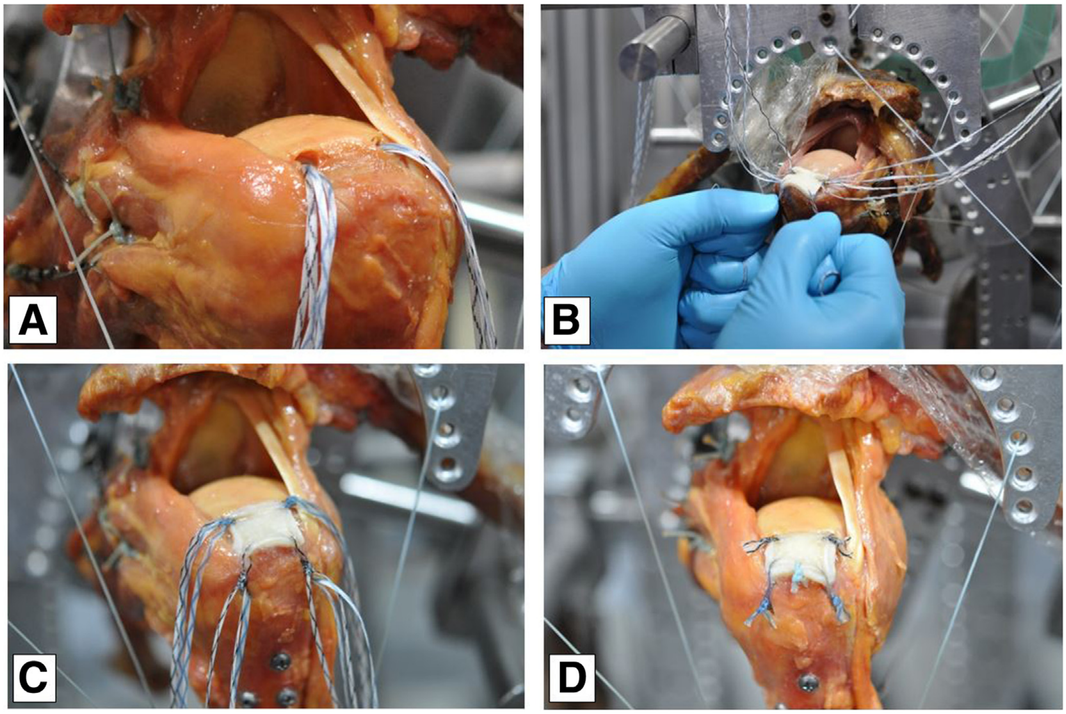

Fig 2. Photographs of a right cadaveric shoulder. (A) After creating a stage III tear, a smooth surface was created on the greater tuberosity so the medial side of the graft was flush with the articular margin of the humerus and medial anchors were placed. (B) Tensioning of the graft to determine lateral anchor placement. (C) Single-layer allograft secured. (D) Double-layer allograft secured.

subacromial space to evaluate the contact mechanics between the humeral head and greater tuberosity against the acromion.[1,26] The Tekscan sensor was calibrated using 2 points, 40 to 60 N calibration, before the experiment with the Instron 3365 load cell (Instron). Sensitivity of the Tekscan was set at 35. Contact pressure was calculated as contact force/contact area. For the subacromial pressure measurements, a 5% bottom filter was used to eliminate the lower range of measurements that could be due to noise of the sensor.

Once the testing was completed, the specimens were disarticulated to free the humeral head from the glenoid, and the articular geometry was digitized relative to the humeral and scapular reference screws using the MicroScribe. The humeral head apex was plotted against the center of the glenoid to determine how the humerus moves relative to the glenoid throughout the range of motion.[33] The humeral head apex shift from intact was calculated by taking the difference between the intact condition and the succeeding conditions. The highest point on the greater tuberosity and the undersurface of the acromion relative to the humerus and scapula reference screws were digitized to calculate the acromiohumeral distance (AHD) using the data of the reference screws recorded during testing.

Statistical Analysis

A sample size calculation was performed with data from the first 2 specimens. Average difference and standard deviation in superior translation at 40° abduction (AB)/30° external rotation (ER) was used to determine the number of specimens needed to achieve a power of 80% and a 95% confidence level. The highest number of specimens needed was calculated to be 7 for the comparison of a stage III tear to a single-layer graft; therefore, we chose to test 8 specimens.

All measurements were performed twice to ensure repeatability, and the mean value was used for data analysis. A linear mixed-effects model analysis of variance with a Tukey post hoc test for pairwise comparisons was performed using RStudio (Posit Software), and statistical significance was defined as $P < .05$. A 2-tailed paired t test was used to assess the significance between the thickness of the graft pre- and post-testing.

Results

Superior Humeral Translation

The stage III tear significantly increased superior translation at 20° and 40° of glenohumeral abduction and all degrees of ER, as well as at 60° AB and 60° ER compared to the intact condition (Fig 3; $P < .045$ for all comparisons). Relative to the tear condition, the single-

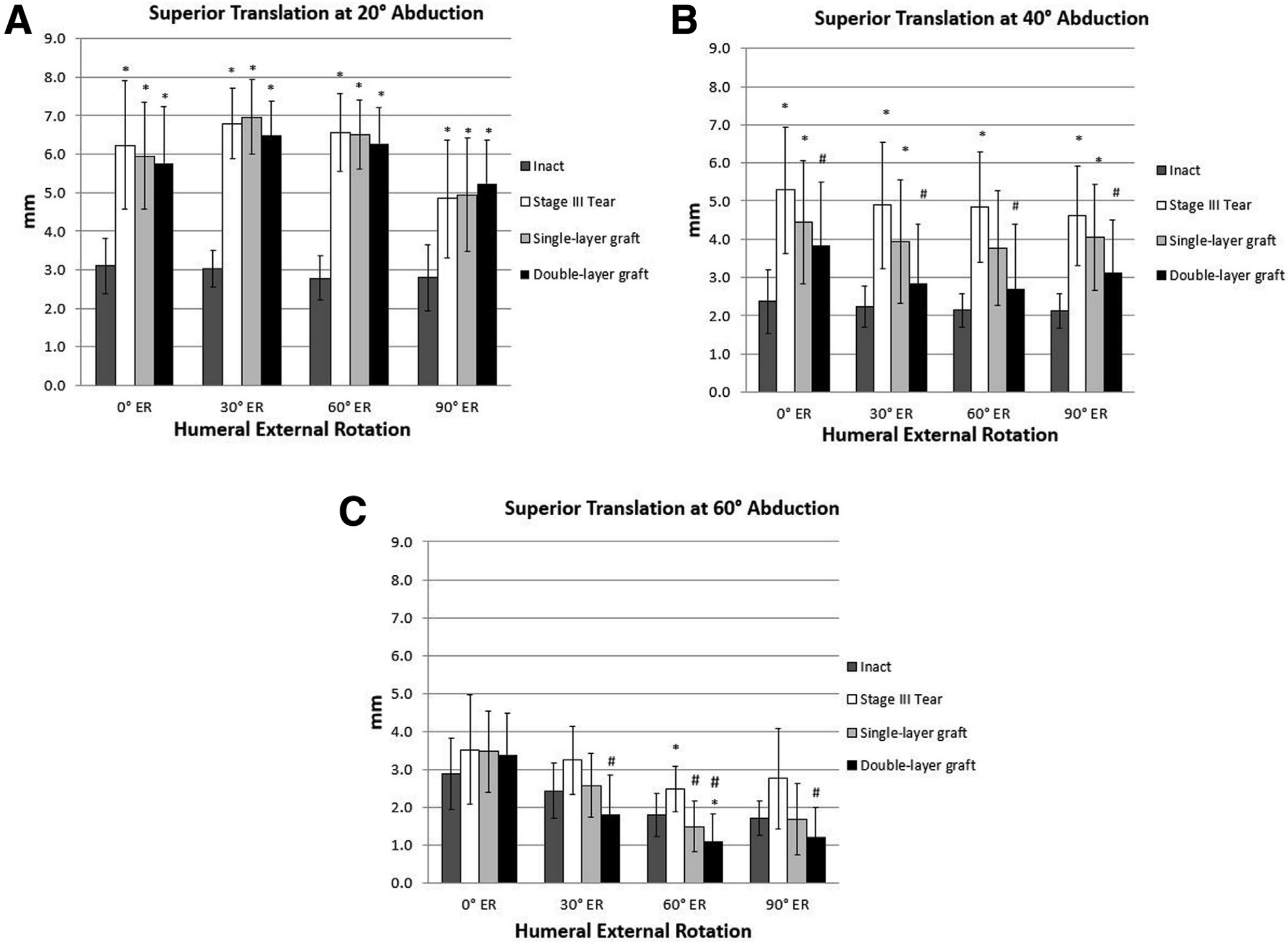

Fig 3. Effect of acellular human dermal allograft tuberoplasty with either a single-layer or double-layer graft on superior translation. Change from superiorly directed unbalanced load to balanced loading condition. (A) 20° of glenohumeral abduction. (B) 40° of glenohumeral abduction. (C) 60° of glenohumeral abduction. Bars represent means, with error bars representing 95% confidence intervals. ER, external rotation. *$P < .05$ vs intact; #$P < .05$ vs stage III tear.

layer AHDAT significantly decreased superior translation at 60° AB and 60° ER ($P = .003$), whereas the double-layer AHDAT significantly decreased superior translation at all ER positions at 40° AB and also at 60° AB/30°, 60°, and 90° ER compared to the tear condition ($P < .028$ vs tear for all positions).

There were no statistical differences between the single-layer and the double-layered AHDAT for all abduction and external rotation angles.

Glenohumeral Kinematics

There were no significant humeral head apex shifts from intact with the stage III tear or the single-layer graft condition; however, the double-layer AHDAT significantly shifted the humeral head apex inferiorly compared to the tear condition and single-layer allograft at both 60° AB and 0° ER ($P = .013$ and $P = .015$) and 60° AB and 30° ER ($P = .013$ and $P = .040$) (Table 1).

Acromiohumeral Distance

The stage III tear significantly decreased the acromiohumeral distance at 20° glenohumeral abduction with balanced ($P < .001$) and unbalanced loading ($P = .002$) and at 40° of glenohumeral abduction with unbalanced loading ($P \leq .002$). The single-layer AHDAT normalized acromiohumeral distance to intact levels for 20° AB with balanced loading ($P \geq .065$ vs intact) and 40° AB with unbalanced loading ($P \geq .409$ vs intact). The double-layer AHDAT restored acromiohumeral distance to intact levels for 20° and 40° AB with unbalanced loading ($P \geq .055$ and .942 vs intact, respectively). At 40° AB with unbalanced loading, there was a significant increase in acromiohumeral distance with the double-layer AHDAT compared to stage III tear ($P = .008$). There were no statistical differences detected between the single-layer and the double-layered AHDAT for all abduction and external rotation angles (Table 2).

Table 1. Change in Superior-Inferior Humeral Head Apex Position From Intact With Balanced Muscle Loading

Testing Position	Stage III Tear, mm	Single-Layer Graft AHDAT, mm	Double-Layer Graft AHDAT, mm
20° Abduction			
0° ER	1.1 ± 1.7	1.2 ± 1.4	1.1 ± 1.7
30° ER	0.5 ± 1.5	0.4 ± 1.3	0.6 ± 1.5
60° ER	0.7 ± 1.7	0.2 ± 0.5	0.7 ± 1.5
90° ER	0.2 ± 0.9	0.2 ± 0.6	0.0 ± 1.3
40° Abduction			
0° ER	0.0 ± 2.9	0.8 ± 1.6	−0.2 ± 2.1
30° ER	0.7 ± 1.2	0.1 ± 0.8	0.0 ± 0.8
60° ER	−0.3 ± 1.3	0.1 ± 1.4	−0.5 ± 1.2
90° ER	−0.7 ± 1.3	−0.6 ± 0.6	−0.7 ± 0.7
60° Abduction			
0° ER	−0.4 ± 0.8	−0.4 ± 0.9	−1.4 ± 1.1*,†
30° ER	−0.1 ± 0.8	−0.2 ± 0.7	−1.0 ± 1.2*,†
60° ER	−0.7 ± 1.3	−0.9 ± 1.0	−1.0 ± 1.2
90° ER	−0.3 ± 1.4	−1.0 ± 1.6	−0.3 ± 0.9

NOTE. Values are given as mean ± standard deviation. + value denotes superior translation; − value denotes inferior translation.

AHDAT, acellular human dermal allograft tuberoplasty; ER, external rotation.

*A significant difference compared to the stage III tear ($P < .05$).

†A significant difference compared to the single-layer tear ($P < .05$).

Subacromial Contact Pressure

The stage III tear significantly increased subacromial contact pressure compared to intact at 0°, 30°, and 60° ER at 20° and 40° AB and 30° ER at 60° AB ($P \leq .034$). The single-layer AHDAT showed no significant difference compared to the intact state in contact pressure at 40° AB and 30° and 60° ER ($P = .216$, .129 vs intact). Similarly, the double-layer AHDAT showed no significant difference compared to the intact state in contact pressure at 20° AB, 0° and 60° ER at 40° AB, 30° and 60° ER, and at 60° AB, 30° ER ($P \geq .051$ vs intact). There were no statistical differences detected between the single-layer and the double-layered AHDAT for all abduction and external rotation angles (Table 3).

Graft Thickness of Single- and Double-Layer AHDAT

The single-layer graft thickness was 2.9 ± 0.4 mm pretesting and 2.4 ± 0.4 mm post-testing. The double-layer graft thickness was 5.0 ± 0.7 mm pretesting and 4.2 ± 0.6 mm post-testing. Both the single- and double-layer grafts showed a significant decrease in graft thickness with testing ($P \leq .003$).

Discussion

In this study, the AHDAT effectively mitigated superior humeral translation in a cadaveric model of a stage III rotator cuff tear. Single- and double-layer AHDAT exhibit comparable biomechanical performance. The observed changes in humeral head apex shifts and acromiohumeral distance restoration, as well as the normalization of subacromial contact pressure, provide insights into the favorable biomechanical effects of AHDAT in this specific rotator cuff tear condition. The observed reduction in graft thickness after testing underlines the importance of considering structural changes over time in the clinical application of AHDAT.

Several treatment options[8-23] reduce pain and improve shoulder functionality in patients with irreparable rotator cuff tears; however, the optimal management of irreparable rotator cuff tears is poorly understood. The biologic tuberoplasty is a potential option because it decreases operating time, technical demand, relative cost, and recovery times.[30] The biologic tuberoplasty procedure serves as an interpositional tissue between the greater tuberosity and the undersurface of the acromion.[10] Prior literature concludes favorable postoperative patient outcomes regarding pain relief, function, range of motion, strength, and satisfaction following tuberoplasty, including biologic tuberoplasty.[10,30,34-36]

In the current study, single- and double-layer dermal allografts were tested in numerous glenohumeral abduction and external rotation positions to determine if the thickness of the AHDAT affected humeral kinematics and subacromial contact pressures. As

Table 2. Acromiohumeral Distance

Testing Position/Loading Condition	Intact, mm	Stage III Tear, mm	Single-Layer Graft AHDAT, mm	Double-Layer Graft AHDAT, mm
20° Abduction				
Balanced loading	9.5 ± 2.0	8.0 ± 2.4*	8.6 ± 2.2	8.5 ± 2.3*
Unbalanced loading	7.6 ± 2.0	5.6 ± 2.2*	6.1 ± 1.9*	6.3 ± 1.9
40° Abduction				
Balanced loading	7.3 ± 1.7	6.9 ± 2.4	6.9 ± 2.1	7.4 ± 2.1
Unbalanced loading	6.2 ± 1.7	4.2 ± 2.1*	5.4 ± 2.1	5.9 ± 2.0†
60° Abduction				
Balanced loading	7.3 ± 1.8	7.3 ± 1.4	7.6 ± 1.6	8.2 ± 1.7*,†
Unbalanced loading	6.5 ± 2.1	5.5 ± 1.8	6.3 ± 1.5	6.4 ± 1.8

NOTE. Values are given as mean ± standard deviation.

AHDAT, acellular human dermal allograft tuberoplasty.

*A significant difference compared to the intact state ($P < .05$).

†A significant difference compared to the stage III tear ($P < .05$).

Table 3. Subacromial Contact Pressure

	Intact		Stage III Tear		Single-Layer Graft AHDAT		Single-Layer Graft AHDAT	
Testing Position	Pressure, kPa	Change in Pressure, %	Pressure, kPa	Change in Pressure, %	Pressure, kPa	Change in Pressure, %	Pressure, kPa	Change in Pressure, %
20° Abduction								
0° ER	164.3 ± 79.4	—	402.4 ± 269.2*	145	378.4 ± 239.1*	130	308.6 ± 151.7	88
30° ER	184.8 ± 30.2	—	422.9 ± 133.5*	129	373.8 ± 121.3*	102	355.8 ± 114.5*	93
60° ER	249.8 ± 114.9	—	439.2 ± 205.7*	76	398.1 ± 134.4*	59	365.3 ± 108.2	46
90° ER	126.2 ± 69.3	—	155.6 ± 142.8	23	143.6 ± 117.9	14	161.6 ± 131.1	28
40° Abduction								
0° ER	163.0 ± 31.2	—	371.3 ± 241.0*	128	348.5 ± 194.4*	114	384.5 ± 141.8*	136
30° ER	332.4 ± 260.0	—	535.0 ± 239.2*	61	469.3 ± 219.6	41	423.9 ± 50.9	28
60° ER	288.7 ± 178.4	—	509.7 ± 277.3*	77	434.9 ± 156.9	51	388.1± 94.0	34
90° ER	123.8 ± 102.2	—	207.3 ± 132.6	67	240.1 ± 188.6	94	251.0 ± 67.7	103
60° Abduction								
0° ER	167.0 ± 92.5	—	182.8 ± 129.1	9	288.7 ± 121.2	73	247.7 ± 98.1	48
30° ER	226.9 ± 42.0	—	409.2 ± 90.4*	80	351.1 ± 78.5*	55	329.5 ± 101.0	45
60° ER	203.7 ± 104.6	—	310.7 ± 217.2	53	288.0 ± 142.9	41	267.1 ± 139.5	31
90° ER	92.7 ± 66.3	—	144.1 ± 115.5	55	194.6 ± 174.9	110	170.0 ± 121.5	83

NOTE. Values are given as mean ± standard deviation. Pressure percentage is the percent change from intact.
AHDAT, acellular human dermal allograft tuberoplasty; ER, external rotation.
*A significant difference compared to the intact states ($P < .05$).

hypothesized, the AHDAT improved the biomechanical characteristics compared to the stage III tear condition. At 20° of abduction, the AHDAT frequently failed to contact the acromion as it was located relatively lateral on the humerus and had not yet reached the impingement angle. The effectiveness of the AHDAT is position dependent, which may result in inconsistent clinical outcomes at abduction angles less than 20°. The double-layer AHDAT primarily demonstrated its effectiveness on superior translation at 40° and 60° of abduction. Notably, at 60° AB/0° ER, there was no significant difference in superior translation between the double-layer AHDAT and the tear condition. This was due to the AHDAT being located anterior and medial to the acromion in this orientation, which causes the acromion to contact other parts of the humerus due to the humeral geometry. Clinically, the impingement between the acromion and the greater tuberosity, occurring due to increased superior humeral translation, presents as pain in irreparable rotator cuff tears.[1,10,24,25] Interpretation of these results suggests that the AHDAT would be most effective at decreasing superior translation at glenohumeral abduction angles greater than 20°, which is more toward a functional range of motion, and that the tissue interposition between the humeral head and the subacromial surface could result in decreased pain.[34-36]

The double-layer AHDAT condition demonstrated a significant change in the humeral head apex inferiorly, compared to the tear and single-layer AHDAT conditions at 60° AB, 0° and 30° ER. Although this finding could lead to abnormal glenohumeral joint kinematics, it is questionable to what degree this has clinical impact given the largest of these shifts from the intact condition was 1.4 ± 0.4 mm ($P < .04$) (Table 1).

In both balanced and unbalanced loading conditions, the single- and double-layer AHDAT increased the AHD from the tear state at every abduction angle but 40° AB with the single-layer AHDAT with balanced loading (Table 2). Analysis of the humeral head apex shift and AHD illustrates the ability of the dermal allograft to prevent superior migration of the humerus after a stage III rotator cuff tear. Although statistically significant, a ∼1- to 2-mm change in AHD may not be clinically significant and requires further study, although prevention of bone-on-bone contact may be the more important variable when utilizing interpositional tissue, rather than the distance measurement itself.

The stage III tear condition significantly increased the subacromial contact pressure (KPa) from the intact state at 20° and 40° AB and 0°, 30°, and 60° ER at as well as 60° AB, 30° ER (Table 3). This was expected since the supraspinatus and the anterior half of the infraspinatus are no longer functioning as stabilizing structures for the shoulder joint, leading to a superior-posterior migration of the humerus; furthermore, the soft tissue interface between the humeral head and the acromion was no longer present. This study highlights the similarities of the single- and double-layer augmentations on contact mechanics after a stage III tear. Both AHDAT conditions normalized contact pressure at 40° AB, 30° and 60° ER. Additionally, the double-layer AHDAT normalized the contact pressure at 20° AB, 0° and 60° ER and 60° AB, 30° ER. Compared to the intact condition, an increase in contact pressure was seen among the single- and double-layer AHDAT. The addition of the AHDAT, an interpositional tissue in the subacromial space, may be able to decrease patient pain by reducing bone-on-bone contact between the acromion and greater tuberosity, even with obligatory increases in pressure from the intact condition.

Patients present with various pathologies, tear sizes, and bone quality, and depending on their status in life, their expectations on postoperative recovery and functionality may vary. While AHDAT may not impact active shoulder functionality, the procedure holds promise as a potential solution for patients experiencing pain due to large, irreparable rotator cuff tears, provided that the individual patient's specific needs and circumstances are carefully considered.

Mirzayan et al.[30] suggested the biologic tuberoplasty would be an effective stand-alone procedure in repairing massive, irreparable rotator cuff tears as it is a quick procedure, less technically demanding, and cost-effective, and it results in a quicker rehabilitation period compared to SCR. Although the findings from this preliminary study are promising, there were limited number of patients observed and a short mean follow-up time.[30] The AHDAT could be considered an adjunct to other anatomic procedures, including but not limited to partial repairs and reconstructions, which have proven to biomechanically improve superior stability of the humeral head; AHDAT as a stand-alone procedure is yet to be validated as higher-powered studies having long-term follow-up are needed.

Limitations

This study has several limitations. First, this study was a cadaveric biomechanical study that cannot simulate healing biology, and the results shown are representative of normalization effects only at time zero. Second, the biological tuberoplasty procedure aims to decrease pain, but this was not possible to assess since we are testing on cadaveric shoulders. Third, knot fixation was used in order to have the fixation points the same for both AHDAT procedures by using double-loaded suture anchors; clinically, a knotless fixation could be performed.[37] Finally, testing was completed only in the scapular plane for the stand-alone AHDAT procedure.

Conclusions

Both single- and double-layer grafts for AHDAT improved superior translation, subacromial contact characteristics, and acromiohumeral distance after a stage III rotator cuff tear, with varying effectiveness due to the position-dependent nature of greater tuberosity to acromial contact with abduction.

Disclosures

The authors report the following potential conflicts of interest or sources of funding: Funding for this study, surgical instruments, and dermal grafts were provided by Arthrex (funding number: AIRR-0092). M.D. reports a relationship with Arthrex that includes employment. O.H. reports a relationship with Arthrex that includes employment. T.Q.L. reports financial support paid to his institution and equipment, or supplies were provided by Arthrex, and a relationship with Arthrex that includes consulting or advisory, funding grants, nonfinancial support, and travel reimbursement. All other authors (R.L., M.P., R.B., M.H.M., G.A.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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