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Original article

Superior capsular reconstruction for irreparable supraspinatus tendon tears using the long head of biceps: A biomechanical study on cadavers

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ABSTRACT

Introduction: The superior articular capsule complements the rotator cuff's function in shoulder stability. With irreparable rotator cuff tears, superior capsular reconstruction (SCR) improves dynamic gleno-humeral (GH) joint kinematics. We present a novel method of SCR in cadaveric shoulders using the long head of bicep (LHB) tendon instead of previously explored fascia lata autograft, thereby reducing harvest site and suture anchor associated complications.
Hypothesis: This novel method of SCR using the LHB is feasible biomechanically in restoring shoulder stability in irreparable supraspinatus tendon tear.
Materials and methods: Seven cadaveric shoulders were tested in a custom shoulder testing system. Superior translation of the humerus, subacromial contact pressure and area, and glenohumeral range of motion were tested at 0°, 30°, and 60° of glenohumeral abduction in the following conditions: (1) intact shoulder, (2) simulated complete supraspinatus tendon tear, (3) modified SCR using LHB, (4) and modified SCR using LHB and side-to-side repair augmentation.
Results: The complete cuff tear shifted the humeral head superiorly as compared to the intact shoulder. Subacromial peak contact pressure was also increased at 30° and 60° while contact area was increased at 0° and 30°. The modified SCR both with and without side-to-side repair shifted the humeral head inferiorly at 30° and 60°, with contact area further reduced at 60°. Both techniques had comparable results for contact pressure and total rotational range of motion.
Conclusion: The LHB with appropriate distal insertion on the greater tuberosity restores shoulder stability in irreparable rotator cuff tears by re-centering the humeral head on the glenoid.
Level of evidence: Basic science study, biomechanical testing.

1. Introduction

Rotator cuff tears are a common source of pain and weakness among the ageing population. As fatty degeneration increases, cuff tendons retract further propagating the tear to an irreparable status, where viable repair of the tendon back to its footprint becomes impossible [1,2]. Incidence of irreparable rotator cuff tears range between 6.5–22.4% [3,4]. As rotator cuff coverage and function is lost, there is an increased superior translation of the humeral head causing subacromial impingement and degeneration of the glenohumeral (GH) joint [5,6]. Superior migration of the humerus with an acromiohumeral interval of < 7 mm on a standard AP shoulder radiograph is highly suggestive of an irreparable rotator cuff tear [7,8]. Once deemed irreparable, surgical options range from debridement, tendon transfers, graft interposition and joint replacement if there is extensive arthritis [3,9,10].

Recent studies have identified the superior capsule of the glenohumeral (GH) joint as a key component in rotator cuff tear management. Patients with irreparable tears have a defect in this capsule located on the inferior surface of the supraspinatus and infraspinatus tendons [11]. Reconstruction of the rotator cuff without repairing the superior capsule has been associated with

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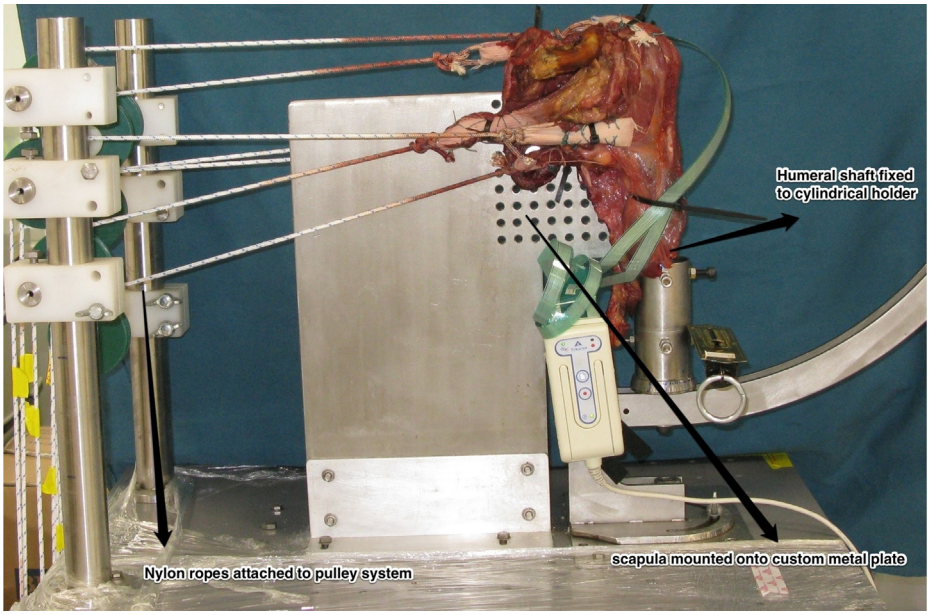

Fig. 1. Set up of custom testing jig.

persistent superior GH instability, impingment and risk of graft damage [12]. The restoration of superior stability is postulated to be essential in improving functional outcomes by the restoration of the acromiohumeral distance [13]. Superior capsule reconstruction (SCR) has been shown to normalize superior translation in a biomechanical study [11] and to increase acromiohumeral distance by 4.1 mm in a clinical study [14]. It improves GH kinematics allowing the deltoid and the remaining cuff to function more effectively [15]. Mihata and colleagues revealed improved functional and radiological parameters for patients with irreparable cuff tears undergoing SCR using a fascia lata autograft [14].

To avoid harvest site complications with use of the fascia lata, we present a novel method of SCR reconstruction using long head of bicep (LHB) tendon. We propose tenotomy of LHB in the bicipital groove with advancement and attachment of the proximal limb of the tenotomy over the torn rotator cuff footprint, thereby reconstituting the superior capsule. In this study, we aim to investigate the biomechanical feasibility of our approach in human cadaveric shoulders.

2. Methods

2.1. Specimen preparation

Seven fresh-frozen cadaveric shoulders from donors aged 50 to 65 year of age at the time of death were thawed overnight at room temperature before dissection and experimentation. Specimens were assessed for any visible abnormality and discarded if any were found. All specimens were dissected free of skin and subcutaneous tissue, and the humerus was transected 2 cm proximal to the lateral epicondyle. The shoulder capsule, coracoacromial ligament, the tendinous insertions of all rotator cuff muscles, and the humeral insertion of the pectoralis major, latissimus dorsi, and deltoid (anterior, middle, and posterior) were preserved.

The scapula was positioned in a custom metal plate using 3 large bolts (Fig. 1). The plate was then fixed to a custom testing jig at 20 degrees of anterior tilt in the sagittal plane. The transected humeral shaft was fixed to a cylindrical holder using screws and cement, allowing humeral axial rotation and glenohumeral abduction (Fig. 1). A goniometer located at the end of the holder allowed measurement of the humeral rotation, and a predetermined torque was directed with a torque wrench to measure rotational range of motion. Nylon ropes were attached to the woven nylon band wrapped and secured around each respective muscle group to stimulate the muscle forces. The nylon band was attached to the muscles by using a Krackow locking running stitch with Ethibond No. 5 suture. Physiological muscle force vectors were applied with adjustable pulleys and weight plates. 0.9% saline solution was used to keep the specimens moist throughout the experiment.

2.2. Testing conditions

We used a similar validated testing condition as Mihata's biomechanical cadaveric study on superior capsular reconstruction in irreparable rotator cuff tears [11]. All measurements were performed at 0°, 30° and 60° of glenohumeral abduction, which corresponded to 0°, 45° and 90° of shoulder abduction. The rotational angle was fixed at 30° of external rotation when all muscle loads were applied [11].

Two different loading conditions were used, as established according to results from the study by Mihata et al. [11]. The first loading condition was to test a balanced loading condition to establish initial position, while the second loading condition demonstrated a superiorly directed muscle loading condition. The following forces were applied for each testing: loading condition 1: deltoid, 40N; pectoralis major, 20N; latissimus dorsi, 20N; supraspinatus 10N; infraspinatus/teres minor, 10N; subscapularis, 10N. For loading condition 2: deltoid, 80N; supraspinatus, 10N; infraspinatus/teres minor, 10N; subscapularis, 10N. The superior translation force was achieved by increasing the deltoid force and unloading the pectoralis major and latissimus dorsi in loading condition 2.

In the first testing condition, the shoulder had an intact rotator cuff as the control. After all measurements were obtained in the intact condition, an irreparable supraspinatus tear was created as the second test condition (Fig. 2). A segment of the supraspinatus and superior capsule were excised from the greater tuberosity insertion laterally to the glenoid medially separating them from the intact infraspinatus and subscapularis tendons [11]. In the third condition, a modified superior capsular reconstruction was performed using the technique as described below. The last

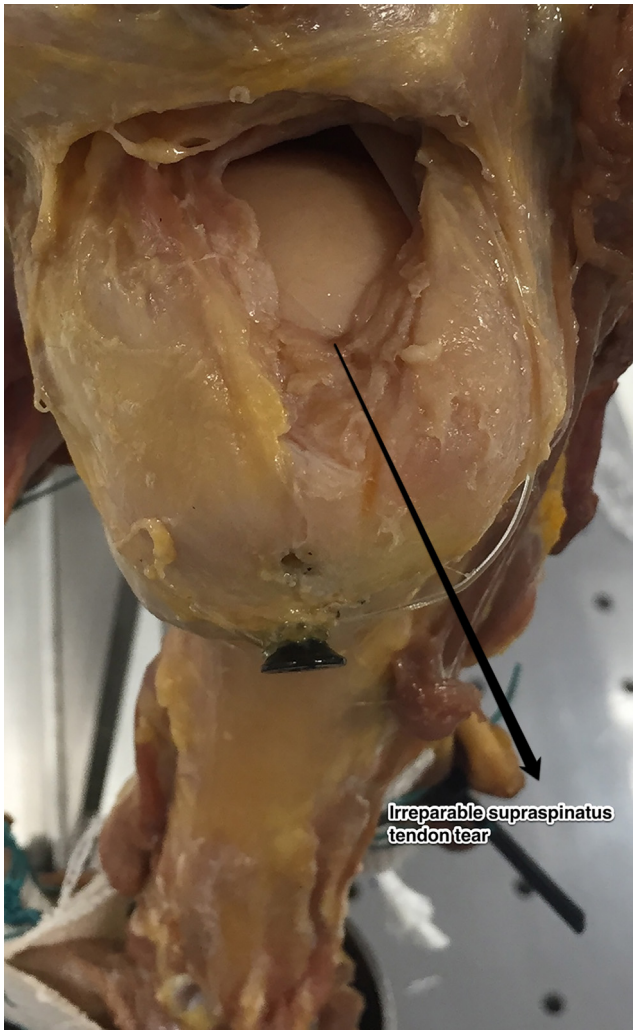

Fig. 2. Creation of irreparable supraspinatus tear.

condition involved a side-to-side repair of the LHB graft to the intact infraspinatus.

The reference plane and coordinate system (x, anterior-posterior; y, superior-inferior; z, medial-lateral) were defined before testing. The initial position of the humeral head in the intact shoulder condition was set to 0 in the x, y and z directions in all testing conditions at 0°, 30° and 60° of glenohumeral abduction in the scapular plane with a 3-dimensional digitizing system [MicroScribe 3-Dimensional Digitizer Immersion Corp, San Jose, California]).

2.3. Measurements

Glenohumeral superior translation, glenohumeral range of motion (ROM), and subacromial peak contact pressure and area were compared among the 4 conditions:

- intact shoulder;
- simulated irreparable rotator cuff tendon tear;
- modified SCR using LHB as proposed in this study;
- modified SCR using LHB with side-to-side repair augmentation to the infraspinatus tendon.

One screw was placed on the anterolateral acromion while the 2nd screw was positioned adjacent to the proximal portion of the bicipital groove, avoiding the biceps tendon (Fig. 3). Superior translation measured the distance between the acromion and the humerus in the superior-inferior direction under loading condition 1 and 2 by recording the distance between the screws with the 3-dimensional digitizing system.

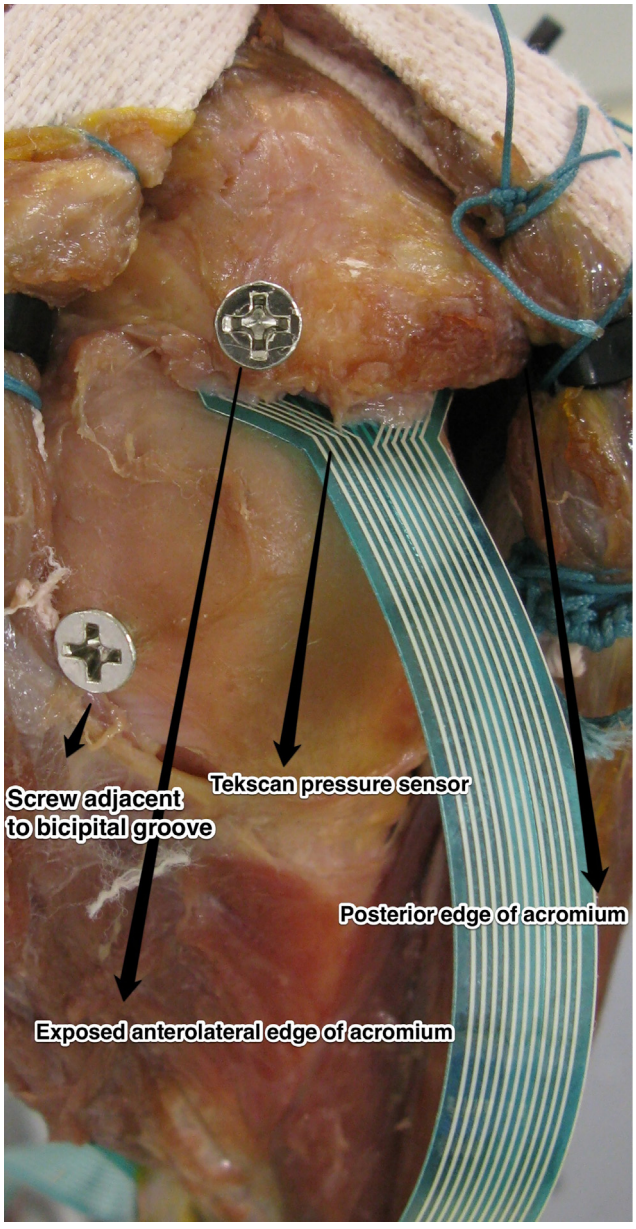

Fig. 3. Positioning of markers for measurement of superior glenohumeral translation.

Glenohumeral total ROM was measured at 0°, 30°, and 60° of glenohumeral abduction by the use of a 360° goniometer located at the end of the cylindrical holder under loading condition 1. The maximum rotation was measured by applying a 2.2 Nm torque. Total ROM was then calculated by adding external and internal ROM.

Subacromial peak contact pressure between the coracoacromial arch and humerus were recorded using a Tekscan pressure sensor ([Saturation pressure, 1100 PSI] [Model 6900, Tekscan, Boston, Massachusetts]) (Fig. 3).

2.4. Modified superior capsular reconstruction using the LHB

The LHB was tenotomised at the point of entrance into the bicipital groove keeping the origin of LHB at the glenoid intact. The

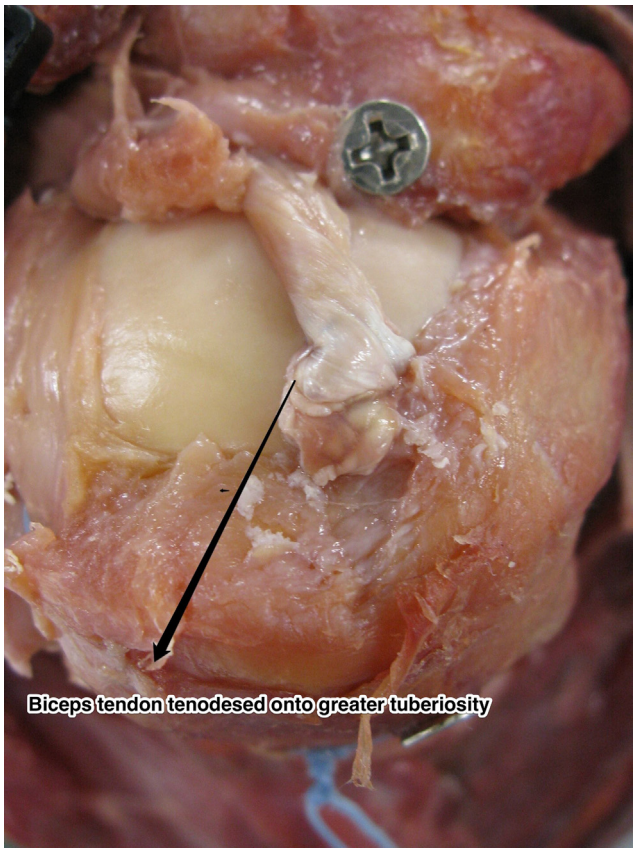

Fig. 4. Modified superior capsular reconstruction via transosseous repair.

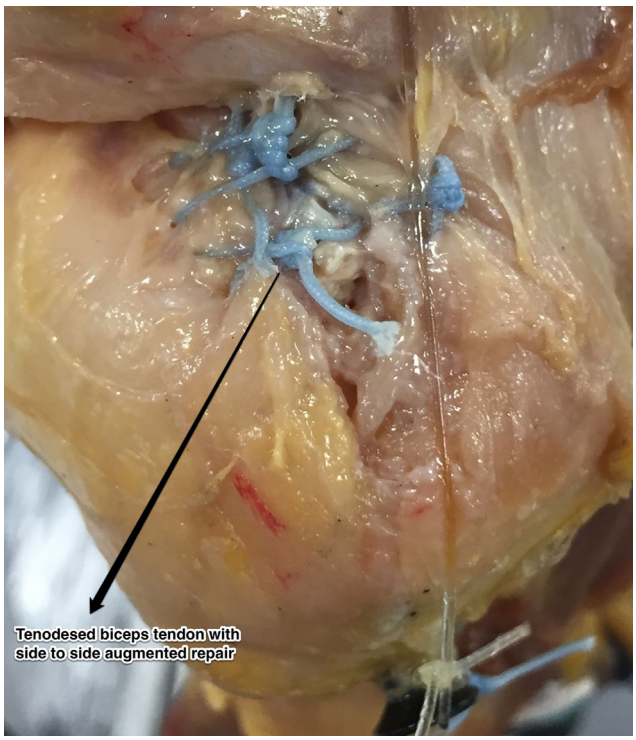

Fig. 5. Modified superior capsular reconstruction with side-to-side repair to infraspinatus and subscapularis.

tenotomised proximal end was secured by a transosseous repair on the greater tuberosity footprint, of the superior capsule [16]. The tendon end was secured using a Krackow locking running stitch with No. 2 Fibre Wire suture (Arthrex, Naples, FL). The LHB was tensioned taut, and transosseous repair was performed with sutures passing through 2 bone tunnels at the greater tuberosity footprint (Fig. 4). Similar to the originally described SCR using a fascia lata graft, the LHB was attached at 30° glenohumeral abduction in the scapular plane (correlating to 45° of shoulder abduction) based on clinical setting [14]. The remnant distal biceps tendon was left free for the experiment.

Finally, for the 4th testing condition, side-to-side sutures were added between the LHB posteriorly to the infraspinatus tendon using the remnant No. 2 Fibre Wire sutures (Fig. 5).

3. Statistical analysis

All measurements were performed twice, and the average was used for data analysis. Statistical analyses were performed using repeated-measures analysis of variance followed by a Tukey post hoc test. Data are presented as means ± standard deviations of the mean. The significance level was set at $p < 0.05$.

4. Results

Compared with intact shoulders, the creation of an irreparable rotator cuff tear shifted the humeral head superiorly at 0° (0.47 mm, $p = 0.973$), 30° (0.94 mm; $p = 0.723$) and 60° (1.12 mm; $p = 0.659$) and increased subacromial peak contact pressure at 30° (219.4%; $p = 0.120$) and 60° (156.0%; $p = 0.694$) of glenohumeral abduction. The contact area was increased at 0° (109.8%; $p = 0.985$) and 30° (110.0%; $p = 0.938$) for the irreparable rotator cuff tear state as compared to those of intact shoulders. The range of motion in a irreparable rotator cuff tear at 0° (90.1%; $p = 0.867$), 30° (90.4%; $p = 0.752$) and 60° (92.4%; $p = 0.870$) were all decreased as compared to that of shoulders with intact tendons (Tables 1–5).

Compared with measurements in shoulders with an irreparable rotator cuff tear, the modified superior capsule reconstruction shifted the humeral head inferiorly at 0° (1.02 mm; $p = 0.959$), 30° (0.72 mm; $p = 0.856$), and 60° (0.47 mm; $p = 0.962$). It also reduced subacromial peak contact pressure at 0° (84.5%; $p = 0.980$) and 60° (85.5%; $p = 0.980$) while at 30°, the pressure was comparable. The contact area after reconstruction was decreased at 60° (64.1%; $p = 0.195$).

The modified SCR with side-to-side repair to the infraspinatus tendon had a similar effect on shoulder stability. As compared to the irreparable rotator cuff tear, it shifted the humeral head inferiorly at 0° (0.52 mm; $p = 0.964$), 30° (1.35 mm; $p = 0.452$), and 60° (1.03 mm; $p = 0.714$). It also reduced subacromial peak contact pressure at 30° (95.6%; $p = 0.102$) and 60° (98.2%; $p = 0.672$). The subacromial contact area was significantly reduced at 60° (51.6%; $p = 0.045$).

The rotation range of motion was decreased after creation of a supraspinatus tendon tear when compared to the shoulders with an intact cuff. The range of motion improved after the SCR at 0º of GH abduction but not at 30° and 60° in abduction. The rotational range of motion improved to normal value at 30° of abduction after a side-to-side repair was carried out between the SCR and the infraspinatus tendon.

There was no significant differences in the parameters studied between the SCR alone and that with the SCR with side-to-side repair to the infraspinatus tendon.

5. Discussion

Superior capsular reconstruction potentially improves function by re-centering the humeral head and improving glenohumeral kinematics. The superior articular capsule occupies 30–61% of the

Table 1
Summary of superior glenohumeral translation in all testing conditions.

	Intact		Supraspinatus tear		*p* (tear vs. intact)	Modified SCR		*p* (SCR vs. tear)	Modified SCR with side-to-side repair		*p* (Mod SCR vs. tear)
GH abduction	Translation (mm)	% Translation	Translation (mm)	% Translation		Translation (mm)	% Translation		Translation (mm)	% Translation	
0	2.33 ± 1.80	100	2.80 ± 2.32	120.3	0.973	1.78 ± 1.84	76.6	0.791	2.28 ± 2.22	98.0	0.964
30	1.84 ± 1.97	100	2.78 ± 2.00	151.6	0.723	2.06 ± 1.45	112.5	0.856	1.43 ± 1.20	77.7	0.452
60	1.24 ± 1.43	100	2.36 ± 1.27	189.5	0.659	1.89 ± 2.89	152.0	0.962	1.33 ± 0.986	107.2	0.714

Table 2
Summary of subacromial peak contact pressure in all testing conditions.

	Intact		Supraspinatus tear		*p* (tear vs. intact)	Modified SCR		*p* (SCR vs. tear)	Modified SCR with side-to-side repair		*p* (Mod SCR vs. tear)
GH abduction	Pressure (MPa)	% Pressure	Pressure (MPa)	% Pressure		Pressure (MPa)	% Pressure		Pressure (MPa)	% Pressure	
0	0.140 ± 0.121	100	0.111 ± 0.0938	79.1	0.954	0.118 ± 0.0812	84.5	0.999	0.143 ± 0.121	102.4	0.937
30	0.206 ± 0.204	100	0.452 ± 0.257	219.4	0.120	0.202 ± 0.153	98.1	0.112	0.197 ± 0.159	95.6	0.102
60	0.132 ± 0.102	100	0.205 ± 0.0924	156.0	0.694	0.113 ± 0.0954	85.5	0.521	0.129 ± 0.187	98.2	0.672

Table 3
Summary of subacromial contact area in all testing conditions.

	Intact		Supraspinatus tear		*p* (tear vs. intact)	Modified SCR		*p* (SCR vs. tear)	Modified SCR with side-to-side repair		*p* (Mod SCR vs. tear)
GH abduction	Area (mm^2)	% of Intact	Area (mm^2)	% of Intact		Area (mm^2)	% of Intact		Area (mm^2)	% of Intact	
0	83.3 ± 34.7	100	91.4 ± 35.7	109.8	0.985	89.6 ± 47.9	107.5	0.999	98.71 ± 52.6	118.5	0.989
30	91.6 ± 37.1	100	101.6 ± 25.0	110.9	0.938	91.3 ± 33.8	99.7	0.933	93.0 ± 32.4	101.6	0.959
60	100.7 ± 41.5	100	101.3 ± 25.5	100.6	0.999	64.6 ± 30.9	64.1	0.184	52.0 ± 31.3	51.6	0.045

Table 4
Summary of total rotational range of motion in all testing conditions.

	Intact		Supraspinatus tear		*p* (tear vs. intact)	Modified SCR		*p* (SCR vs. tear)	Modified SCR with side-to-side repair		*p* (Mod SCR vs. tear)
GH abduction	ROM (Degree)	% of Intact	ROM (Degree)	% of Intact		ROM (Degree)	% of Intact		ROM (Degree)	% of Intact	
0	93.6 ± 10.7	100	84.3 ± 24.9	90.1	0.867	95.7 ± 29.5	102.3	0.779	92.9 ± 20.6	99.2	0.891
30	111.4 ± 13.5	100	100.7 ± 20.1	90.4	0.752	97.9 ± 26.4	87.8	0.993	112.9 ± 18.2	101.3	0.649
60	94.3 ± 26.2	100	87.1 ± 12.2	92.4	0.870	85.0 ± 15.8	90.2	0.797	90.7 ± 15.1	96.2	0.981

Table 5
Modified SCR vs. modified SCR with side-to-side repair.

	Superior shift, mm			Subacromial peak contact pressure (% of intact values)		
GH abduction	Modified SCR	Modified SCR with side-to-side repair	*p* values	Modified SCR	Modified SCR with sside-to-side repair	*p* values
0	1.78 ± 1.84	2.28 ± 2.22	0.968	0.118 ± 0.0812	0.143 ± 0.121	0.970
30	2.06 ± 1.45	1.43 ± 1.20	0.894	0.202 ± 0.153	0.197 ± 0.159	0.999
60	1.89 ± 2.89	1.33 ± 0.986	0.937	0.113 ± 0.0954	0.129 ± 0.187	0.994
	Subacromial contact area (mm^2)			Total rotational range of motion (% of intact values)		
GH abduction	Modified SCR	Modified SCR with side-to-side repair	*p* values	Modified SCR	Modified SCR with side-to-side repair	*p* values
0	89.6 ± 47.9	98.71 ± 52.6	0.979	95.7 ± 29.5	92.9 ± 20.6	0.995
30	91.3 ± 33.8	93.0 ± 32.4	0.999	97.9 ± 26.4	112.9 ± 18.2	0.514
60	64.6 ± 30.9	52.0 ± 31.3	0.890	85.0 ± 15.8	90.7 ± 15.1	0.574

greater tuberosity in areas where rotator cuff tendinous insertions are relatively deficient, complementing the rotator cuff's function [16]. Mihata and colleagues used a fascia lata autograft for SCR and showed significant improvement in functional scores at 2-year post surgery [14]. Follow-up MRIs revealed that 83% of patients had intact reconstructions with no progression of muscle artrophy [14]. Fascia lata harvest, though a simple procedure, does involve an incision further away from the index surgery, contributing to an additional pain site. There is also the added drawback of donor site morbidity such as scarring, scar sensitivity, hematoma formation, muscle herniation and infection [17–19]. Wheatcroft et al. reported that 67% of the patients complained of pain on walking lasting from 1 to 30 days, and 38% reported limping between 1–14 days following surgery [20]. There was also a significantly high risk of wound

pain in 57% of the patients and unsightly thigh scarring in 38% of the study population [20]. Dubiel and Wigren reported muscle herniation in 36% of the patients, weakness of hip flexion, numbness, pain, haemorrhage, superficial phlebitis, and wound infection after harvesting a 10 × 20 cm area of fascia lata [18].

The long head of the biceps tendon has been used previously to bridge gaps in massive rotator cuff tears. Rhee et al. [9] had used the tenotomised biceps tendon to bridge cuff defects in 31 shoulders. The procedure was performed open in 15 cases, and arthroscopic in the remaining 16 patients. At a mean follow-up of 32 months they reported excellent and good UCLA scores in 90.3% of their patients. Sano et al. [21] performed a similar procedure occasionally splitting the tenotomised intraarticular LHB tendon to bridge cuff defects and reported improved total Japanese Orthopaedic Association scores from 54.7% points to 83.1 points. Cho et al. [22] used the LHB tendon to augment cuff repairs to avoid undue tension in the tissue. They reported fewer structural failures and significant improvement in muscle strength in comparison to traditional repairs without augmentation. However, Mihata et al. [11] have shown inferior results with patch grafting of cuff defects when performed in isolation, as subacromial contact pressure was not reduced in a cadaveric study. With reconstruction of the superior capsule that pressure was reduced to normal [11]. Also superior humeral translation was better reduced with SCR than with patch grafting of the torn rotator cuff in that study [11].

In our study we have used the LHB tendon in reconstructing the superior capsule of the glenohumeral joint. It is a naturally available tissue. The origin of the LHB from the glenoid is at the spot used to anchor the fascia lata graft in Mihata's reconstruction of the superior capsule [11,14,15]. All that is done with our procedure is a tenotomy of the biceps tendon in the bicipital groove and reattaching the tendon further posteriorly over the footprint of the supraspinatus tendon at the greater tuberosity. The distal biceps tendon in either left free or tenodesed to the bicipital groove. Murthi et al. [23] have shown that the intraarticular portion of the LHB tendon was healthy in patients with cuff tears. The unhealthy segment was in the bicipital groove. We therefore have used the healthy tendon in our reconstruction as have others [9,21,22], when they used the tenotomised tendon as an interposition graft.

Our experiment showed that resection of the supraspinatus tendon resulted in superior displacement of the humeral head. Mihata et al. [11] also showed significant superior translation of the humerus once the supraspinatus tendon was cut. Similar to our study they also showed an increase in subacromial contact pressure [11] at 0° and 30° of glenohumeral abduction. In our study increased subacromial contact pressure was at 30° to 60° of abduction. SCR using a 8 mm thick fascial lata graft decreased subacromial contact pressure and superior translation of the humeral head in the study by Mihata et al. [15]. Our study using the LHB had reduced superior humeral head translation and reduced subacromial contact pressures at 0° and 60° of glenohumeral abduction, but results were not statistically significant. By adding a posterior side-to-side suturing Mihata et al. showed a further inferior shift of the humeral head [11]. In our study we also showed a further inferior shift of the humerus with both anterior and posterior side-to-side suture to the LHB tendon, but the results were not statistically significant.

Mihata et al. [15] had suggested that the ideal fascia lata graft for SCR should be 8 mm thick and the distal attachment of the graft should be with the glenohumeral joint in 10° to 30° of abduction. The LHB tendon closely matches the recommended dimension and its attachment on the greater tuberosity in easily adjusted to be with the glenohumeral joint abducted 10° to 30°.

Mihata et al. used a free fascial lata graft in the SCR [11,12,14,15]. Our use of the LHB still attached to the glenoid allows the maintenance the neural and vascular elements in the graft. We could expect a better durability of our graft compared to a free graft. Also the technical execution of the surgery, we expect would be comparatively easier with our technique of reconstruction, which may be performed arthroscopically if necessary.

Mihata's free fascia lata graft needs to be protected by side-to-side suture to the adjacent infraspinatus being as it is avascular and aneural. Our technique using a vascularised and more importantly neurotised graft has intrinsic in built safety against failure with time as reflex mechanisms can come in to play to activate the remaining rotator cuff musculature during deltoid contraction.

Weaknesses in our study are limitation due to our cadaveric design. Cadaveric specimens do not account for biological healing potential. Our results, therefore, demonstrated biomechanics at time zero after surgery and do not take into account the subsequent scarring and healing. Another limiting factor is the simple section of the supraspinatus tendon. In vivo, supraspinatus rupture occurs on a degenerative tendon and the retraction occurs gradually with muscle and capsuloligament adaptations which may explain why the values we have measured were not significant between the situation "intact" and the situation "supraspinatus tear". It would have been more representative to find cadavers with already retracted supraspinatus tendon tears, and not one that is surgically created. In cases of massive rotator cuff tears, the LHB maybe be torn intraarticularly, which makes this procedure infeasible. Also, we did not test the LHB as a free interposition graft as did Mihata with fascia lata graft. Compounded by the small sample size, we have failed to show any significant difference in our results. However, this study has given us useful information that the modified SCR approach can potentially restore superior stability to the humeral head and reduce subacromial contact pressure and area. A subsequent clinical study will be performed after this cadaveric work to determine the clinical outcome of our approach for treating irreparable rotator cuff tears in the hope of addressing this limitation.

6. Conclusion

SCR using the LHB restores shoulder stability in specimens with irreparable supraspinatus tendon tears. With lower risk of complications such as harvest-site morbidity, we believe this modified SCR using the LHB is a feasible alternative in the management of irreparable rotator cuff tears.

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contribution

All the authors contributed equally in the design of the study and preparation of this manuscript.

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