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Graft-Augmented Repair of Irreparable Massive Rotator Cuff Tears with Latissimus Dorsi Transfer to Treat Pseudoparesis

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Background: Irreparable massive rotator cuff tears are characterized by a poor prognosis with high failure rates following repair. Numerous strategies, such as partial repair, graft interposition, latissimus dorsi (LD) transfer, balloon arthroplasty, and superior capsular reconstruction, have been proposed. We have adopted a graft-augmented LD-transfer procedure, in which partial repair, graft interposition, and LD transfer are performed simultaneously.

Methods: Thirty-nine patients underwent the graft-augmented LD-transfer procedure using autologous fascia lata from 2007 to 2016. All patients underwent a 5-year assessment at a mean (and standard deviation) of 54.8 ± 3.5 months. Of 20 patients with a history of >10 years, 14 underwent a 10-year assessment at a mean of 112.6 ± 5.6 months. To characterize the therapeutic effects of the procedure, the patients were divided into 3 groups according to the tear pattern: superior-posterior tears (Group A), superior-anterior tears (Group B), and global tears (Group C).

Results: The overall mean Constant-Murley score improved from 33.8 ± 5.3 preoperatively to 63.1 ± 9.4 at the 5-year assessment ($p < 0.001$). The overall mean active anterior elevation (AE) improved from 57.3° ± 13.2° preoperatively to 131.3° ± 18.2° at 5 years ($p < 0.001$). Preoperatively, AE was significantly different between Groups A and C ($p < 0.001$) and between Groups B and C ($p < 0.001$), reflecting the difference in cuff tear patterns. Postoperatively, AE was significantly higher in Group A than in Groups B ($p < 0.001$) and C ($p < 0.001$). The present study also showed that AE was electromyographically synchronized to the contraction of the transferred LD. The transferred LD was kinetically more potent at a slower speed, but it was easier to exhaust, than the native rotator cuff. Osteoarthritis progression was radiographically found to occur during the first 5 years.

Conclusions: The graft-augmented LD-transfer procedure may be a treatment option for massive rotator cuff tears, especially for active patients who are <60 years old.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Massive rotator cuff tears (RCTs) are commonly defined as full-thickness tears involving ≥2 tendons or tears measuring >5 cm[1,2]. Superior humeral migration can lead to pseudoparesis, in which arm elevation is severely disabled[2,3]. Massive RCTs are associated with a poor prognosis and high failure rates following repair[4]. Their stumps are so retracted that they are "irreparable." Irreparable massive RCTs are associated with grade-3 or 4 fatty infiltration according to the Goutallier classification system[5].

Partial repair[6,7], graft interposition[8,9], latissimus dorsi (LD) tendon transfer[10,11], balloon arthroplasty[12,13], and superior capsular reconstruction[14,15] have been proposed. However, it is currently not possible to recommend for or against any specific strategies. We use a graft-augmented RCT repair using autologous fascia lata with LD reinforcement, in which partial repair, graft interposition, and LD transfer can be simultaneously performed.

There is a paucity of comparative evidence to guide clinical decision-making in the treatment of massive irreparable RCTs[16]. Our first objective was to determine whether the RCT pattern was associated with functional outcomes as determined by the Constant-Murley (CM) score and anterior elevation (AE).

Second, we performed electromyographic examination of the shoulder muscles to determine whether contraction of

Disclosure: The **Disclosure of Potential Conflicts of Interest** form is provided with the online version of the article (http://links.lww.com/JBJSOA/A343).

TABLE I Characterization of Massive Cuff Tears According to the Cuff Tear Pattern and the Response to the Graft-Augmented LD Transfer at the 5-Year Assessment*

Patients with Massive RCTs (>5 cm) Involving ≥2 Tears of the SSC, SSP, and ISP	Overall (N = 39)	Tear Pattern (N = 39)			P Value		
		Group A (Superior-Posterior Pattern)† (N = 19)	Group B (Superior-Anterior Pattern)‡ (N = 14)	Group C (Global Pattern)§ (N = 6)	A vs. B	B vs. C	A vs. C
Occurrence of combined SSC rupture							
Upper SSC	51.0%	0.0%	100.0%	100.0%			
Lower SSC	15.0%	0.0%	35.7%	16.7%			
Mean rotator muscle fatty infiltration grade[5]#							
SSC (0-4)	2.0	0.7	3.1	3.3			
SSP (0-4)	3.5	3.5	3.6	3.5			
ISP (0-4)	2.8	3.4	1.7	3.3			
TM atrophy (0-1)	0.2	0.26	0.00	0.33			
Mean AHI *(mm)*							
Preop.	2.0	2.2	1.9	1.8			
Postop.	8.9	8.9	9.3	8.2			
Mean Hamada[20] classification (preop.)**	2.0	2.0	2.0	2.0			
CLEER occurrence	13%	15.8%	0.0%	33.3%			
Mean CM score (0-100)							
Preop.	33.8	34.5	33.7	31.7	0.48	0.073	<0.001
Postop.	63.1	65.3	61.1	60.7	<0.001	0.68	0.049
Mean VAS pain score (0-19)							
Preop.	2.5	3.2	2.4	0.7	0.08	<0.001	<0.001
Postop.	1.5	1.8	1.2	1.3	0.11	0.68	0.12
Mean anterior elevation *(deg)*							
Preop.	57.3	62.4	57.5	40.7	0.054	<0.001	<0.001
Postop.	131.3	145.8	120.4	110.8	<0.001	0.054	<0.01
Mean external rotation *(deg)*							
Preop.	17.7	14.7	27.5	4.2	<0.001	<0.001	0.14
Postop.	32.6	31.2	43.2	12.5	<0.001	<0.001	<0.001

*SSC = subscapularis tendon, SSP = supraspinatus tendon, ISP = infraspinatus tendon, TM = teres minor, AHI = acromiohumeral interval, CLEER = combined loss of elevation with external rotation, and VAS = visual analog scale. †Group A involved no SSC rupture and represented the superior-posterior tear pattern. With average ISP fatty infiltration of 3.4 and TM atrophy of 0.25, 15.8% of patients exhibited CLEER. ‡Group B involved a 100% rupture of the upper SSC and ISP fatty infiltration of <2 and represented the superior-anterior pattern. With average ISP fatty infiltration of 1.7 and TM atrophy of 0.0, none of the patients exhibited CLEER. §Group C involved 100% rupture of the upper SSC and ISP fatty infiltration of >3 and represented the global pattern. With average ISP fatty infiltration of 3.3 and TM atrophy of 0.33, 33.3% of patients exhibited CLEER. #Fatty infiltration of the rotator muscles was graded from 0 to 4, according to the Goutallier classification system[5], but TM atrophy was graded as present (1) or none (0) on T2-weighted sagittal MRI. **Cuff tear arthropathy was graded from 0 to 5, according to the Hamada classification system[20].

the transferred LD was synchronized to AE. We examined the shoulders radiographically to assess whether AE followed the physiological kinetics and whether osteoarthritis had progressed radiographically. We investigated the clinical, electromyographic, and radiographic outcomes at 5 and 10 years.

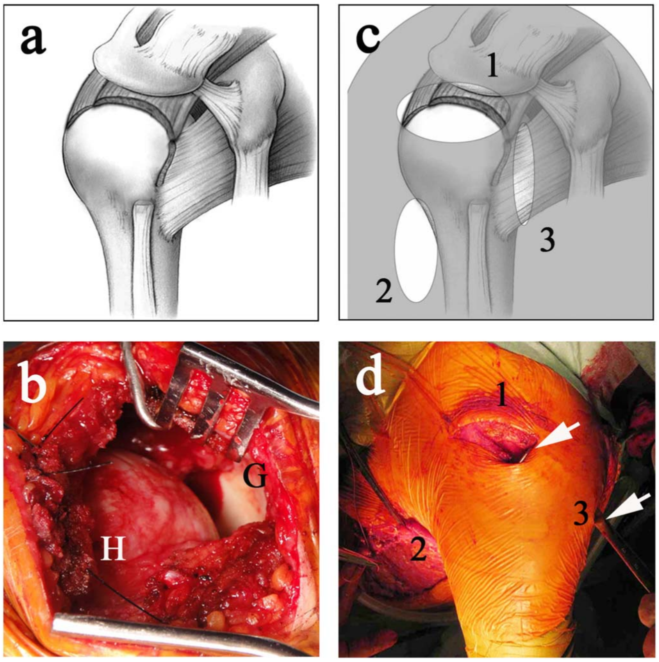

Fig. 1

Figs. 1-A through 1-D Graft-augmented LD transfer with the window positions. **Fig. 1-A** Illustration showing a complete rupture of the SSP and ISP tendons with partial rupture of the SSC tendon, for which the present graft-augmented LD transfer is indicated. **Fig. 1-B** The glenohumeral joint, consisting of the glenoid (G) and humerus (H), was approached through the first window. **Fig. 1-C** A schematic demonstration of a 7-cm superolateral skin incision creating the first window (1), a 15-cm posterior skin incision along the lateral border of the LD creating the second window (2), and a 7-cm deltopectoral incision creating the third window (3). **Fig. 1-D** An intraoperative view demonstrating the first (1), second (2), and third (3) windows. A subdeltoid tunnel has been already created from the first to the third windows, through which a retractor is inserted (arrows).

Materials and Methods

Patients

The study was completed after institutional review board approval, and the patients provided consent to participate. Inclusion criteria were massive RCTs of >5 cm and involving ≥2 tendons with full passive and active scapular plane abduction of <90°. Patients fulfilling the criteria who were <60 years old were consecutively treated from 2007 to 2016. The patients were divided according to the tear pattern into 3 groups: Group A included superior-posterior tears (n = 19); Group B, superior-anterior tears (n = 14); and Group C, global tears (n = 6).

Fatty infiltration was classified as grade 0 through 4 for supraspinatus (SSP), infraspinatus (ISP), and subscapularis (SSC) tears[5]. Teres minor (TM) atrophy was staged 0 or 1, corresponding to whether atrophy was present (1) or absent (0) on the T1-weighted sagittal magnetic resonance imaging (MRI) scan (Table I). Group A had no SSC rupture and represented the superior-posterior tear pattern. Three of the 19 patients exhibited a combined loss of elevation with external rotation (CLEER).

Group B had RCTs with a 100% rupture of the upper SSC and fatty infiltration of the ISP of <2, representing the superior-anterior tear pattern. None of the 14 patients exhibited CLEER. Group C had RCTs with a 100% rupture of the upper SSC and fatty infiltration of the ISP of >3.0, representing the global tear pattern. Two of the 6 patients exhibited CLEER (Table I).

Surgery and Postoperative Rehabilitation

The glenohumeral joint was accessed through the first window (Video 1, Figs. 1-A and 1-B) via a 7-cm superolateral incision (Figs. 1-C and 1-D). The SSP was mobilized through the first window (Fig. 2-A), and the SSC was mobilized through the third window (Fig. 2-B), by means of a 7-cm deltopectoral incision (Figs. 1-C and 1-D). The long head of the biceps tendon was prepared for tenodesis (Fig. 2-B). The SSP was not retrievable and was prepared for securing of the graft in all 39 patients (Fig. 2-C).

First, the ISP was partially secured to the greater tuberosity (GT) through the first window and the SSC was secured to

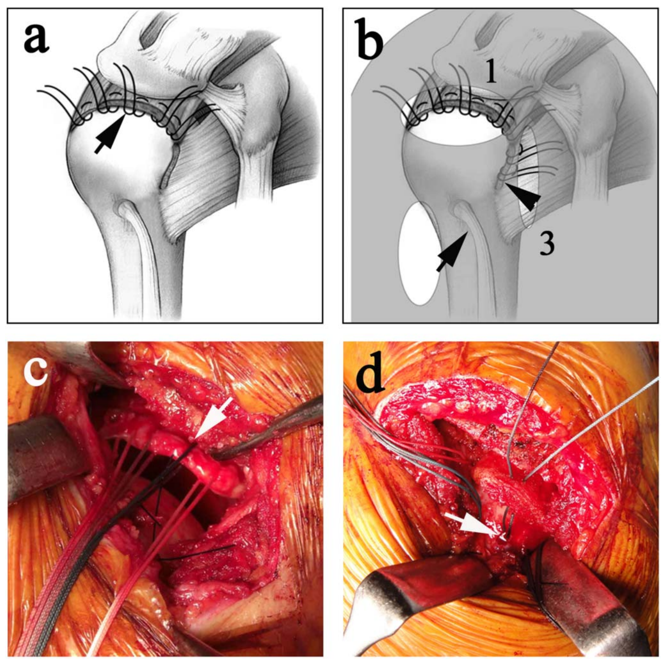

Fig. 2

Figs. 2-A through 2-D Mobilization of the SSP and partial repair of the SSC tendons. **Fig. 2-A** The SSP tendon is mobilized through the first window (arrow). **Fig. 2-B** The SSC tendon is mobilized through the third window (3) and is connected to the first window (1) and is partially secured to the lesser tuberosity (LT) using suture anchors (arrowhead). The long head of the biceps tendon is incised and processed for subsequent tenodesis (arrow). **Fig. 2-C** The SSP tendon is prepared for graft-securing with number-2 nonabsorbable composite sutures (arrow). **Fig. 2-D** The SSC tendon is partially secured using suture anchors to the LT (arrow). Although the inferior portion of the SSC tear has been secured (arrow), the upper portion of the SSC tendon remains detached; however, it is later closed by suturing with the graft.

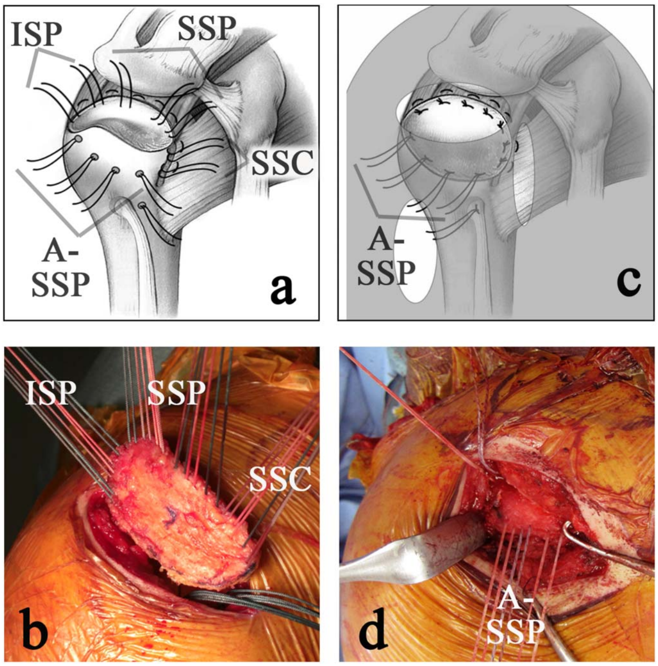

Fig. 3

Figs. 3-A through 3-D Enhancement of tissue strength and protection of the LD tendon with grafting. **Fig. 3-A** The graft was sized to the 3 free edges of the defect (SSP, ISP, and SSC) with sutures coming from anchors (A-SSP) inserted in the greater tuberosity. **Fig. 3-B** The graft is approaching the 3 free edges of the defect (SSP, ISP, and SSC). **Fig. 3-C** The graft is secured laterally to the GT with suture anchors (A-SSP), with the stump of the long head of the biceps tendon secured for tenodesis. **Fig. 3-D** Uncut sutures (A-SSP) are passed through the first window for subsequent securing of the transferred LD tendon.

the lesser tuberosity (LT) through the third window (Fig. 2-D). The SSC was not retrievable in 2 patients in Group B, while the ISP was not retrievable in 2 patients in Group C. In cases of an ISP or SSC that is not retrievable, the graft was secured to the free edges of either the ISP or the SSC.

The graft was secured medially to the free edge of the SSP and was secured laterally to the GT (Figs. 3-A and 3-B). The anchored sutures were left uncut but were passed through the first window for subsequent securing of the transferred LD (Figs. 3-C and 3-D).

Second, the LD was released through the second window (Fig. 4-A) via a 15-cm posterior skin incision along the lateral border of the LD (Figs. 1-C and 1-D). The thoracodorsal artery was explored, and its serratus branch was identified (Fig. 4-B) and ligated for elongation of the LD excursion (Fig. 4-C and 4-D).

Third, a subdeltoid tunnel was created from the second to the third window via the first window (Fig. 5-A). The LD tendon was drawn out of the third window (Fig. 5-B). By the uncut sutures (Fig. 3-D), the transferred LD was intermediately secured to the GT (Fig. 5-C). After applying baseball sutures on both edges of the free end of the LD, the LD was split into 2 strands. Then, they were secured anteriorly and anterolaterally to the LT (Figs. 5- and 5-C). Tendon excursion of >10 cm must be confirmed at the first window level (Fig. 5-D).

Postoperatively, the arm was placed in an arm brace at 45° of abduction and 45° of external rotation (ER) for 5 weeks, according to the original description by Gerber et al.[17]. Biofeedback rehabilitation was provided in both auditory and visual ways (Video 2). Strengthening exercises were started using the PrimusRS system (BTE) in the third month. Postoperative rehabilitation was continued until the sixth to the ninth month.

Clinical, Radiographic, Kinetic, and Electromyographic Assessments

The patients rated the overall results as excellent, good, fair, or unsatisfactory. Shoulder function was scored according to the CM system[18]. Preoperative and 1-year postoperative MRI scans were performed in all 39 patients (Fig. 6-A). Routine clinical and radiographic assessments (Fig. 6-B) of the early group of 20 patients were performed every year. Active range of motion was measured with a goniometer.

Eleven patients consented to having additional postoperative MRI scans at 3, 5, or 10 years postoperatively (Figs. 6-C, 6-D, and 6-E). Radiographic analysis consisted of grading glenohumeral osteoarthritis according to the system of

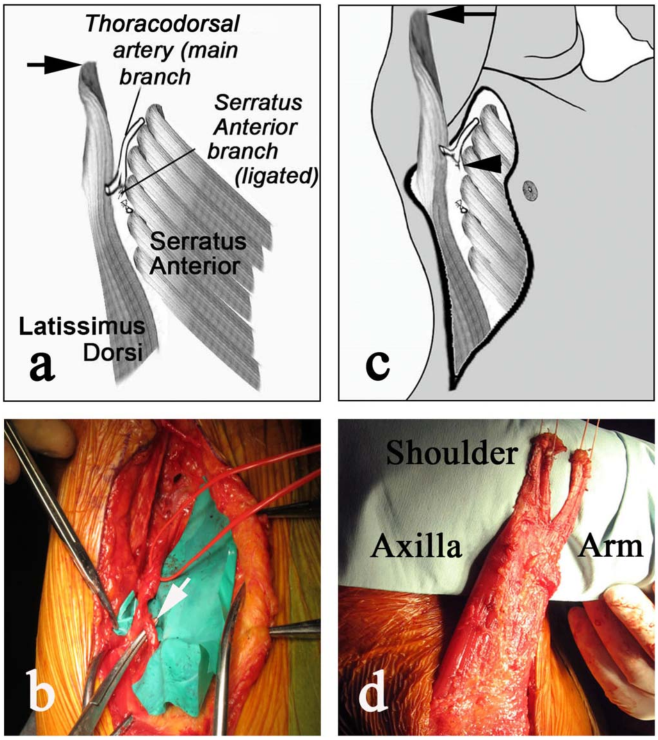

Fig. 4

Figs. 4-A through 4-D Preparation of the LD through the second window. **Fig. 4-A** The thoracodorsal artery supplying the LD and the serratus anterior muscles appears after the release of the LD tendon from the humerus (arrow). **Fig. 4-B** Identification of the serratus branch (arrow) and measurement of its length. **Fig. 4-C** Ligation of the serratus branch (arrowhead) allowing elongation of the LD excursion (arrow). **Fig. 4-D** The elongated LD muscle reaching far beyond the humeral head.

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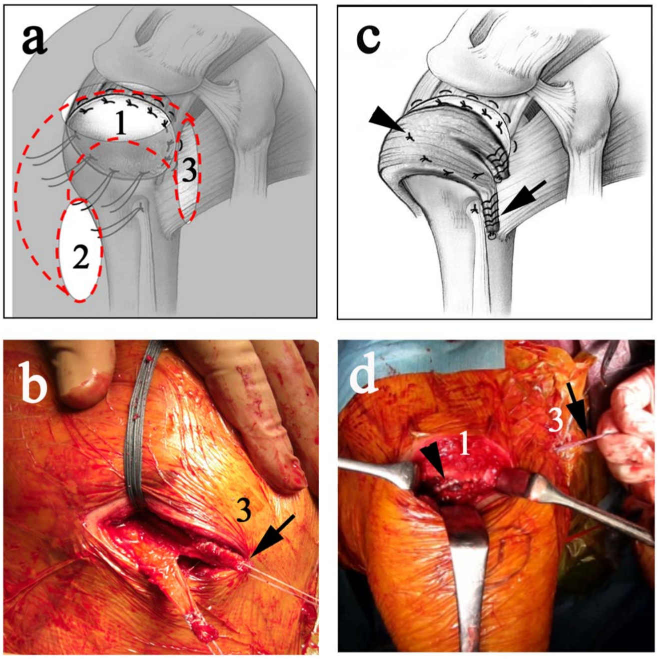

Fig. 5

Figs. 5-A through 5-D Creation of the subdeltoid tunnel and pulling the LD through the tunnel. **Fig. 5-A** A subdeltoid tunnel is created from the second (2) to the third window (3) via the first window (1). **Fig. 5-B** The tendon stumps (arrow) are grasped by number-2 braided nonabsorbable sutures in a baseball suture manner and are pulled through the third window (3). **Fig. 5-C** The transferred LD is intermediately secured to the GT (arrowhead) with its tendon stump terminally secured to the LT (arrow). **Fig. 5-D** Tendon excursion of >10 cm is confirmed through the first window immediately before securing to the GT and the LT. The length of tendon excursion (arrowhead) is confirmed, while pulling number-2 braided nonabsorbable sutures (arrow).

Samilson and Prieto[19] and measuring the acromiohumeral interval (AHI) (Figs. 6-B and 6-F).

Nine patients consented to having true anteroposterior radiographs made of both shoulders at 10°, 45°, 90°, and maximum abduction measured at either 3 or 5 years postoperatively. A kinetic analysis compared the shoulders that had LD transfer and the nontreated shoulders by calculating the β angle (i.e., the inclination of a line crossing the superior and inferior poles of the glenoid facet) and the α angle (i.e., the presumed glenohumeral angle = lateral elevation angle − β angle).

Kinetic analysis for ER was performed with the shoulder laterally elevated at 60° using the PrimusRS system. Maximum strengths (in N) were measured at angular velocities of 30°/sec, 60°/sec, and 90°/sec. Total work (in J) was measured at different angular velocities, indicating how much strength and work the LD exerts during a slow motion, an intermediate-speed motion, and a fast motion. Values were rated as the percentage of those of the contralateral, nontreated shoulders.

Synchronicity of the transferred LD was compared with that of the anterior deltoid, posterior deltoid, and pectoralis major muscles using surface electromyography (EMG) (12-channel EMG, Neuropack X1 MEB-2312; Nihon Kohden).

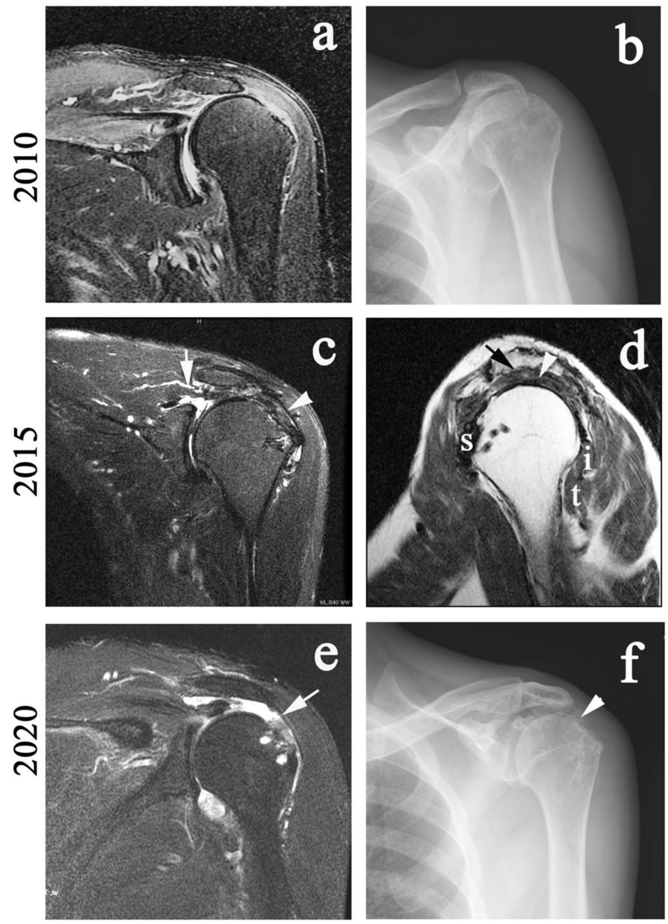

Fig. 6

Figs. 6-A through 6-F MRI scans and radiographs of a 58-year-old man who was followed for 10 years after the graft-augmented LD-transfer procedure. **Figs. 6-A and 6-B** Preoperative oblique coronal T2-fat suppression MRI scan demonstrates a far-reaching retraction of the SSP tendon (**Fig. 6-A**) and an anteroposterior radiograph shows an almost diminished acromiohumeral interval (**Fig. 6-B**). **Figs. 6-C and 6-D** At the 5-year assessment, an oblique coronal T2-fat suppression MRI scan shows that the SSP tendon is very loose (arrow), suggesting rupture of the graft-SSP connection; however, the graft-LD composite (arrowhead) remained intact (**Fig. 6-C**), and an oblique sagittal T1-weighted MRI scan shows the intact graft (arrowhead) and LD (arrow) composite (**Fig. 6-D**). S = subscapularis, i = infraspinatus, and t = teres minor. **Figs. 6-E and 6-F** At the 10-year assessment, the T2-fat suppression MRI scan shows the ruptured graft-LD composite (arrow) (**Fig. 6-E**), and the radiograph shows the development of arthritis with irregular ossification (arrowhead) around the humeral head (**Fig. 6-F**).

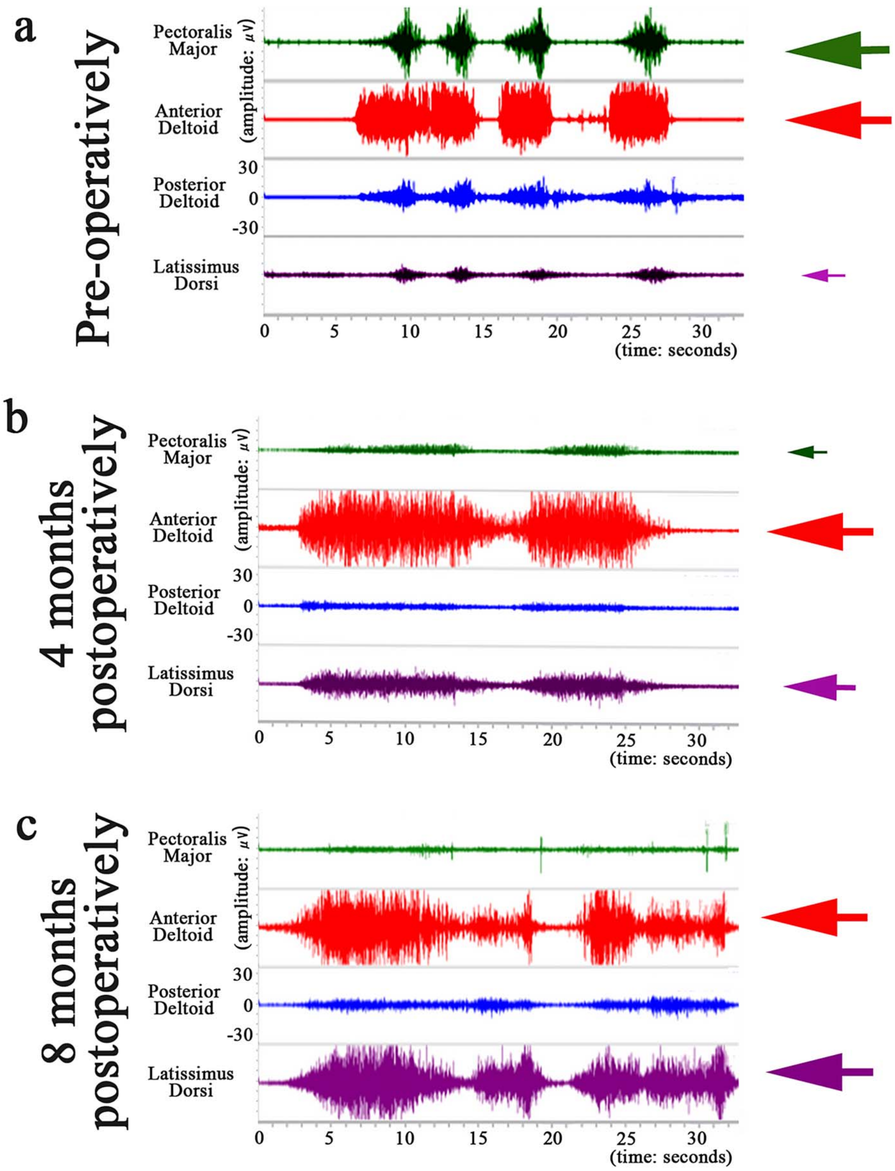

Fig. 7

Figs. 7-A, 7-B, and 7-C Electromyographic changes during postoperative rehabilitation. **Fig. 7-A** Preoperative electromyographs show that the pectoralis major potential (green arrow) was unintendedly synchronized to that of the anterior deltoid (red arrow) as the patient attempted to elevate the arm. **Fig. 7-B** At 4 months postoperatively, the unintended pectoralis major potential (green arrow) is attenuated in magnitude and the potential of the transferred LD appeared (purple arrow). **Fig. 7-C** At 8 months postoperatively, the unintended pectoralis major potential (green arrow) had disappeared, and the potential of the transferred LD had increased in magnitude (purple arrow).

Statistical Analysis

The paired Student t test was used to evaluate the significance of the difference between the preoperative and postoperative values of each measured variable. The level of significance was set at $p < 0.05$. Evaluation of whether active contraction was synchronized with elevation was done qualitatively by graphing the patterns of contraction and associated elevation.

Source of Funding

There was no external funding source.

Results

Patient Series

A total of 39 patients (12 female and 27 male) underwent the graft-augmented RCT repair with LD reinforcement from April 2007 to March 2016. Twenty underwent the procedure in the period from 2007 to early 2012, while 19 had the procedure from late 2012 to 2016. All 39 patients underwent a 5-year assessment at a mean (and standard deviation) of 54.8 ± 3.5 months postoperatively.

Of the 20 patients seen in the early part of the series, 3 patients moved away and 3 died of unrelated causes. The

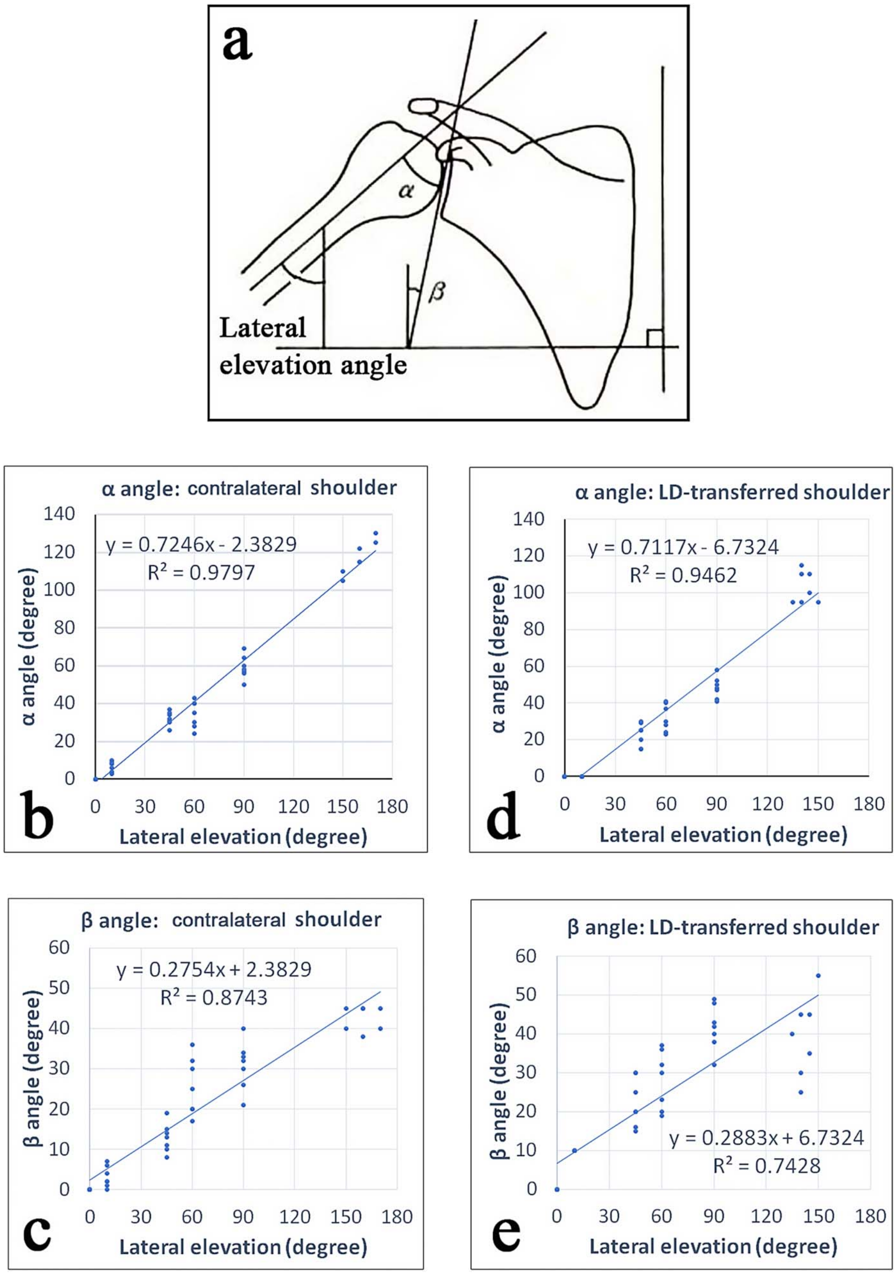

Fig. 8

Figs. 8-A through 8-E Radiographic analysis of glenohumeral-scapular movement in lateral elevation. **Fig. 8-A** Dynamic anteroposterior radiographs of both shoulders made at 10°, 45°, and 90° of lateral elevation and the maximum lateral elevation were used. The glenohumeral-scapular rhythm of the shoulders with LD transfer was compared with that of nontreated shoulders by calculating the β angle and α angle. (The β angle is the inclination of a line crossing the superior and inferior poles of the glenoid facet, and the α angle is the presumed glenohumeral angle, which is the lateral elevation angle minus the β angle.) **Fig. 8-B** Linear regression for the α angle of the contralateral, untreated shoulder demonstrates that the α angle at 0°of lateral elevation was −2.38°. **Fig. 8-C** Linear regression for the β angle of the contralateral, untreated shoulder demonstrates that the β angle at 0° of lateral elevation was +2.38°. **Fig. 8-D** The estimated increase of the α angle of the shoulder with LD transfer starts later than that of the contralateral shoulder. **Fig. 8-E** The estimated increase of the β angle of the shoulder with LD transfer starts earlier than that of the contralateral shoulder.

remaining 14 patients underwent a 10-year assessment at a mean of 112.6 ± 5.6 months (range, 102 to 136 months) postoperatively. At the 10-year assessment, 10 of the 14 patients were rated as having a good outcome; 4, a fair outcome; and 0, an unsatisfactory outcome. The average ISP fatty infiltration and TM atrophy of the 3 subgroups were 3.4 and 0.26,

TABLE II Kinetic Characterization of Shoulder Motion After Treatment with 3-Window LD Transfer*

Angular Velocity	Percentage of Maximum Strength of Healthy, Contralateral Shoulder†	P Value	Percentage of Total Work of Healthy, Contralateral Shoulder†	P Value
30°/sec	112.9 ± 14.5		74.4 ± 22.9	
60°/sec	110.7 ± 11.7		86.3 ± 19.4	
90°/sec	87.6 ± 23.6		83.7 ± 9.2	
30°/sec vs. 90°/sec		<0.001		0.66

*Kinetic analysis demonstrated that the transferred LD can exert more forceful external rotation at 30°/sec, but its percentage of total work remains smaller than any percentage of total work of the healthy, contralateral shoulder. †The values are given as the mean and the standard deviation.

respectively, for Group A; 1.7 and 0.0 for Group B; and 3.3 and 0.33 for Group C.

Clinical and Functional Scores

The overall mean CM score improved from 33.8 ± 5.3 preoperatively to 63.1 ± 9.4 at the 5-year assessment ($p < 0.001$; Table I). The mean CM score was maintained at 61.4 ± 9.8 at the 10-year assessment. The overall mean AE increased from 57.3° ± 13.2° preoperatively to 131.3° ± 18.2° at the 5-year assessment ($p < 0.001$; Table I). The AE was maintained at 125.6° ± 15.5° at the 10-year assessment. The overall mean ER increased from 17.7° ± 9.2° preoperatively to 32.6° ± 8.4° at the 5-year assessment ($p < 0.001$; Table I). The ER was maintained at 29.6° ± 15.5° at the 10-year assessment.

In turn, Group A had significantly better mean postoperative AE than Group B, at 145.8° ± 11.4° versus 120.4° ± 5.29°, respectively ($p < 0.001$), although the mean preoperative AE was not significantly different, at 62.4° ± 4.36° versus 57.5° ± 2.03° ($p = 0.054$; Table I). Group A had a significantly better mean postoperative CM score than Group B, at 65.3 ± 11.4 versus 61.1 ± 5.29 ($p < 0.001$); however, the mean preoperative CM scores were not significantly different, at 34.5 ± 3.20 versus 33.7 ± 3.3 ($p = 0.48$; Table I). These data indicate that Group A had good outcomes, whereas Groups B and C had inferior outcomes.

Electromyographic and Radiographic Assessments

Electromyographic changes during postoperative rehabilitation showed that the synchronized contraction of the transferred LD occurred in parallel with the recovery of arm elevation (Fig. 7, Video 2).

Analysis of the α and β angles showed nonphysiological glenohumeral-scapular movement of the shoulders with LD transfer (Video 2). Inclination of the scapula, which is measured by the β angle, started earlier in the shoulders with LD transfer than in the untreated, contralateral shoulders (Fig. 8). In turn, the increase in the glenohumeral angle, measured by the α angle, started later in the shoulders with LD transfer than in the untreated, contralateral shoulders.

Maximum isokinetic strengths (in N) of ER at each angular velocity (30°/sec, 60°/sec, and 90°/sec) were expressed as the mean percentage of that of the untreated, contralateral shoulder (Table II), indicating how forcefully the shoulder can rotate externally at a slow speed (30°/sec), an intermediate speed (60°/sec), and a fast speed (90°/sec). None of the contralateral shoulders had pseudoparesis,

TABLE III Comparison of Gains of Clinical Scores and Active AE and ER with Inclusion Criteria of RCTs*

	Gains from Preop. to Postop. Values			Inclusion Criteria for Massive RCTs		
	Clinical Score†	Active AE	Active ER	SSP Tear of >5 cm	≥2 Tears Involved	Fatty Infiltration Grade of >3
Group A in present study	+30.8	+83.4°	+16.5°	Yes	Yes	Yes
Partial repair[6,7]	+32.0	+30.0°	+11.0°	Yes	Yes	Yes‡
Graft interposition[8,9]	+42.0	+61.0°	+12.0°	Yes	Yes	NS
LD transfer[10,11]	+28.0	+43.0°	+15.0°	Yes	Yes	Yes
Balloon arthroplasty[12,13]	+29.0	+58.0°	NS	Yes	Yes	Yes
SCR[14,15]	+57.0	+57.0°	NS	Yes§	Yes#	Yes§

*AE = anterior elevation, ER = external rotation, RCT = rotator cuff tear, SSP = supraspinatus tendon, LD = latissimus dorsi, NS = not specified, and SCR = superior capsular reconstruction. †The CM scoring system[18] was used for all studies except those involving SCR, which used the American Shoulder and Elbow Surgeons score ‡Inclusion criteria according to Pandey et al.[7] §Inclusion criteria according to Pennington et al.[15] #Inclusion criteria according to Mihata et al.[14].

although they were not examined in detail with MRI. The maximum strength of the shoulders with LD transfer was larger than that of the contralateral shoulders at the slow speed, 112.9% ± 14.5% of the untreated shoulder, but decreased to 87.6% ± 23.6% ($p < 0.001$) as the speed of rotation increased from 30°/sec to 90°/sec.

The total work of the shoulders with LD transfer was smaller than that of the untreated, contralateral shoulders (Table II) and remained unchanged irrespective of the speed of motion: mean, 74.4% ± 22.9% at 30°/sec, 86.3% ± 19.4% at 60°/sec, and 83.7% ± 9.2% at 90°/sec ($p = 0.66$ for difference between 30°/sec and 60°/sec). These findings indicate that the transferred LD is more forceful but easier to exhaust than the native rotator muscles.

Preoperatively, the overall mean AHI was 2.0 ± 0.5 mm (range, 1.0 to 3.4 mm), corresponding to grade 2 of the Hamada cuff tear arthropathy classification system[20] (Table I). Preoperatively, no shoulder had Hamada grade 3, which displays so-called acetabularization of the acromion (Table I). However, the mean osteoarthritis grade progressed from 0.3 ± 0.22 preoperatively to 1.88 ± 0.36 at the 5-year assessment ($p < 0.001$). Progression was documented in 17 shoulders, with 12 shoulders demonstrating 2 grades of progression and 5 demonstrating 1 grade of progression (Figs. 6-A through 6-F). Osteoarthritis grading at the 5-year assessment (1.88 ± 0.36) was not significantly different from that at the 10-year assessment (2.14 ± 0.43) ($p = 0.076$).

Intraoperatively, the thickness of the graft-LD composite reached a total of 7 to 9 mm with a 3 to 4-mm-thick fascia graft and a 4 to 5-mm-thick LD, which was placed to occupy the subacromial space. No rupture of the transferred LD occurred at the 1-year evaluation (0%; 0 of 20 shoulders) or the 3-year evaluation (0%; 0 of 11 shoulders). However, rupture was noted in 5 of 11 shoulders at 5 years postoperatively and in all 6 shoulders at 10 years postoperatively. The rupture appeared to take place at the musculotendinous junction in the LD, although only 6 of 20 patients with 10-year postoperative evaluations were examined. Despite the progressive rupture of the LD (Figs. 6-A, 6-C, and 6-E), the distal ends of the graft-LD composite always remained in the subacromial space (Fig. 6-E).

Discussion

To treat relatively young patients who have pseudoparesis with irreparable RCTs, we adopted a graft-augmented LD transfer, in which partial repair, graft interposition, and LD transfer are performed simultaneously. The present study demonstrated that the overall mean CM score increased from 33.8 ± 5.3 preoperatively to 63.1 ± 9.4 at the 5-year evaluation. The overall mean AE increased from 57.3° ± 13.2° preoperatively to 131.3 ° ± 18.2° at 5 years, and the mean ER increased from 17.7° ± 9.2° preoperatively to 32.6° ± 8.4° at 5 years (Table I).

The present cohort was divided into 3 subgroups according to the tear pattern: superior-posterior tears composed Group A; superior-anterior tears, Group B; and global tears, Group C (Table I). Then we compared the clinical outcomes (i.e., gains in the CM score, AE, and ER) of the previously reported 5 therapeutic strategies, the inclusion criteria of which were clearly stated and similar to those of Group A[6-15], with the clinical outcomes of Group A (Table III).

When applied to Group A, the graft-augmented LD transfer procedure showed the largest gains in active AE and ER of +83.4° and +16.5°, respectively. According to a systematic review[21], AE in patients after "LD transfer alone" typically showed a gain of +30° to +40°. Compared with other therapeutic modalities (Table III), graft interposition resulted in a gain of +61.0°, which was the largest AE gain[8,9]. Partial repair resulted in a gain of +30.0°, whereas "LD transfer alone" resulted in a gain of 43.0° (Table III). In the current study, partial rotator cuff repair reinforced with LD transfer and graft augmentation appeared to result in a greater gain of active elevation of 83.4° compared with previous approaches.

On the basis of MRI findings, Ernstbrunner et al.[22] recently differentiated massive RCTs with active abduction of <45° (type A) from massive RCTs with abduction between ≥45° and <90° (type B). They showed that type-A RCTs were associated with a fatty infiltration grade of >3 involving >50% of the SSC and concluded that type A is an absolute contraindication to LD transfer alone as it cannot restore normal motion, while type B was well managed with conventional LD transfer alone[22].

The MRI findings in Group C in the present study correspond to the type-A RCTs in the study by Ernstbrunner et al., while the Group-A RCTs in the present study correspond to type B in the study by Ernstbrunner et al. Perhaps the Group-B RCTs in the present study correspond to a point between the Ernstbrunner type-A and type-B RCTs.

We admit that the graft-augmented LD-transfer procedure does not restore normal shoulder motion, but the transferred LD may act as a kind of tenodesis against some unidentified muscle actions. Biomechanically, the transferred LD causes an anteroinferior translation[23]. The present PrimusRS kinetic analysis also showed an increased rotatory force by the transferred LD (Table II). Nonphysiological motions of the scapula are well known with LD transfer[24]. These nonphysiological motions may explain the increased frequency of osteoarthritis and tendon failure.

Limitations of the present study include the small number of cases. Another limitation is the lack of a control group. Restoration of the range of motion was dependent on acquisition of nonphysiological motion by rehabilitation. Improvement of the clinical score may have been limited by the increased osteoarthritis progression with residual pain. Another potential limitation of the study resulted from the fact that the clinical evaluations at the 3 time points were not performed by the same examiner. However, the present graft-augmented LD transfer appears to be a viable treatment option, particularly for active patients who are <60 years old, and results in improvement in functional outcome scores and active AE. The use of the human dermal allograft as an alternative to fascia lata autograft may simplify the procedure; however, verification is needed. ■

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