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Isolated Latissimus Dorsi Transfer versus Combined Latissimus Dorsi and Teres Major Tendon Transfer for Irreparable Anterosuperior Rotator Cuff Tears

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Background: Irreparable anterosuperior rotator cuff tears (IASRCTs) present significant challenges, especially in young, active patients with limited joint-preserving options. Recently, latissimus dorsi (LD) transfer and combined latissimus dorsi and teres major (LDTM) transfer have gained attention as a potential surgical option. We aimed to compare the clinical and radiological outcomes of LD versus combined LDTM transfer in IASRCTs.

Methods: In this retrospective comparative study, 53 patients with IASRCTs were analyzed after undergoing either LD transfer attached to lesser tuberosity (LT) (LD group, n = 23) or combined LDTM transfer attached to greater tuberosity (GT) (LDTM group, n = 30). Clinical evaluations included the visual analog scale score for pain, active shoulder range of motion (ROM), University of California Los Angeles Shoulder Score, American Shoulder and Elbow Surgeons score, activities of daily living that require active internal rotation (ADLIR) scores, and subscapularis (SSC)-specific examinations. Radiographic analyses involved assessing acromiohumeral distance (AHD), Hamada grade, the rate of anterior glenohumeral subluxation reduction, and integrity of the transferred tendon.

Results: Postoperatively, both groups demonstrated significant improvements in pain and clinical scores ($p < 0.001$). At the 2-year follow-up, the LDTM group showed superior internal rotation strength ($p < 0.001$), ADLIR score ($p = 0.017$), and SSC-specific physical examination results (belly-press, $p = 0.027$; bear-hug, $p = 0.031$; lift-off, $p = 0.032$). No significant changes in AHD or Hamada grade were observed in either group. At final follow-up, no significant differences were found between the 2 groups in terms of AHD ($p = 0.539$) and Hamada grade ($p = 0.974$). Although preoperative anterior glenohumeral subluxation was improved in both groups, the LDTM group showed a statistically significantly higher rate of restoration compared to the LD group ($p = 0.015$).

Conclusions: While both LD and combined LDTM transfers for IASRCTs improved postoperative pain relief, clinical scores, and active ROM, the combined LDTM transfer attached to GT was superior to LD transfer attached to LT in terms of internal rotational strength, ADLIR score, and SSC-specific examinations. Neither group showed significant progress in cuff tear arthropathy or decreased AHD at 2-year follow-up; however, the combined LDTM transfer notably improved preoperative anterior glenohumeral subluxation.

Keywords: *Rotator cuff injuries, Subscapularis, Tendon transfer, Latissimus dorsi, Teres major*

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Irreparable anterosuperior rotator cuff tears (IASRCTs) pose significant clinical challenges, involving concurrent tears in the supraspinatus (SSP) and subscapularis (SSC) tendons.[1,2] These tears often lead to substantial functional impairments, such as diminished active internal rotation (IR) and shoulder elevation.[3] IASRCTs are reportedly more prevalent than isolated irreparable SSC tendon tears. Nevertheless, the best treatment strategy for this complex issue continues to be a subject of ongoing discussion.[4,5]

Current treatment options for IASRCTs are limited, and joint-preserving approaches are highly sought in young and active patients. Although arthroscopic debridement and partial repair may alleviate pain, they typically yield only modest improvement in muscle strength and range of motion (ROM).[6] Superior capsular reconstruction (SCR) has been promising for managing irreparable rotator cuff tears, demonstrating favorable early clinical results. However, its application is generally not recommended for patients with IASRCTs, particularly those involving irreparable SSC tears.[7,8]

Anterior latissimus dorsi (LD) tendon transfer has been proposed to manage irreparable SSC tears owing to its biomechanical advantage, specifically its line of pull compared to the pectoralis major (PM) tendon transfer with promising clinical outcomes.[9-11] Additionally, biomechanical studies have demonstrated that LD tendon transfer has a better IR moment arm compared to that of PM transfer, regardless of the attachment site.[12] Nevertheless, Elhassan et al.[11] have noted the limited effectiveness of LD tendon transfer for concurrent irreparable SSP and SSC tears, particularly in improving superior humeral translation and preventing anterior migration. In addition, it was proposed that modification of surgical technique involves attaching the LD tendon transfer to the SSP footprint on the greater tuberosity (GT) rather than to the conventional site on the lesser tuberosity (LT) at the SSC footprint. This adjustment is aimed at improving IR and enhancing overall shoulder stability.[11] Additionally, for cases where isolated LD transfer is insufficient to stabilize the shoulder joint and to improve internal rotation strength, combining it with teres major transfer has been suggested for its synergistic stability effects with scapulohumeral kinematics.[13,14)]

However, to date, there has been no comparative study conducted on patients with IASRCT between the LD transfer attached to the LT and the combined latissimus dorsi and teres major (LDTM) transfer attached to the GT. Therefore, we aimed to compare the clinical and radiological outcomes of LD transfer attached to LT versus combined LDTM transfer attached to GT in patients with IASRCTs. Our hypothesis posited that combined LDTM transfer attached to GT would significantly enhance IR strength, related clinical scores and physical examinations, and anterior glenohumeral stability when compared to LD transfer attached to LT.

METHODS

The Public Institutional Review Board designated by the Ministry of Health and Welfare approved this study (No. P01-202309-01-028). Informed consent was acquired prior to their involvement. This study was conducted in accordance with the tenets of the Declaration of Helsinki.

We performed a retrospective clinical comparative study of patients who underwent LD or combined LDTM transfer between January 2013 and May 2021. Between 2013 and 2015, we performed LD transfer attached to the LT for IASRCTs. Between 2016 and May 2021, combined LDTM transfer attached to the GT was favored because it offered benefits in terms of tendon tensioning and a synergistic muscle pull line, along with biomechanical advantages related to TM tendon's scapulohumeral kinematics. The surgical indications of LD and combined LDTM tendon transfer were as follows: (1) patients experiencing significant pain or notable loss of shoulder function impacting daily life; (2) individuals diagnosed with isolated irreparable SSC or combined irreparable SSC and SSP tears, verified preoperatively (Lafosse type 3 or 4 for SSC, Goutallier fatty infiltration [FI] grade III or IV for SSC and/or SSP, and Patte classification grade III for SSP on magnetic resonance imaging [MRI]) and during surgery; (3) those with intact or reparable infraspinatus (ISP) and teres minor (Tm) evidenced by Goutallier FI grade II or less in preoperative MRI scans; (4) patients without advanced glenohumeral joint arthritis, as confirmed by radiographs (Hamada classification grade II or less; during surgical evaluation, cuff tendons were classified as irreparable if the retracted tendons could not be mobilized to their original footprint despite employing various mobilization techniques and soft-tissue releases); and (5) those with no neuromuscular disease or injury without pseudoparalysis that was defined as active elevation < 45° with full passive elevation after pain relief from local anesthetic injection.[15] Exclusion criteria for the study included (1) patients with isolated irreparable SSC tears and (2) inability to undergo preoperative MRI evaluation and clinical assessment both before and at 2 years postoperatively. Out of 78 patients, 36 and 42 underwent LD and LDTM surgery, respectively. Within these groups, 20 individuals with isolated SSC tears (LD group, 11; LDTM group, 9) were excluded, as were those lacking

2-year follow-up clinical and radiologic data (LD group, 2; LDTM group, 3). Finally, patients who underwent LD transfer (LD group; n = 23) and combined LDTM transfer (LDTM group; n = 30) for the IASRCTs were included (Fig. 1).

Surgical Techniques

For the surgical procedure, under general anesthesia and an interscalene block, the patient was positioned in the beach-chair configuration. All surgical procedures were executed by a single orthopedic surgeon (CHB) utilizing the standard deltopectoral method. Unless the long head of the biceps tendon ruptured, a tenotomy or tenodesis was performed for all patients. Careful identification and protection of the musculocutaneous and axillary nerves were ensured. A comprehensive evaluation was conducted on each patient to assess the feasibility of repairing the remaining SSC and SSP tendons. The assessment involved determining the reparability of these tendons by examining whether retracted cuff tendons could be successfully mobilized and brought back to their original footprint area, even after employing mobilization techniques and adhesion release methods. In instances where satisfactory repair of the SSP was achieved, even after a tendon transfer procedure, such patients were classified as having isolated irreparable SSC tears and excluded from this study. Conversely, if the SSC was satisfactorily repaired, the case was categorized as an isolated SSP tear and alternative surgical procedures, such as SCR, were pursued. Notably, cases were identified where ISP tears were observed, despite the preoperative assessment indicating intact integrity of the ISP tendon and FI grade with Goutallier II or less. In such instances, attempts were made to repair the ISP, and successful repair was accomplished for all patients. Following the determination that the SSC and SSP tendons were found as irreparable tears, the process of harvesting either the LD or LDTM tendon commenced. This involved releasing the proximal end of the PM tendon from its humeral attachment, thereby exposing the underlying insertion points of the LD and TM tendons.

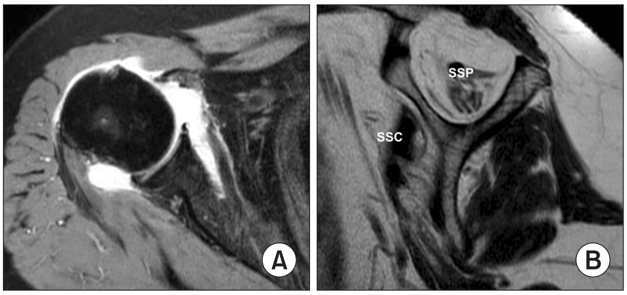

Fig. 1. Preoperative magnetic resonance imaging (MRI) evaluation. (A) Axial T2-weighted MRI of the left shoulder displayed a torn and medially retracted subscapularis (SSC) tendon, denoted by an asterisk. (B) Sagittal oblique T1-weighted MRI showed significant fatty infiltration in both the SSC and supraspinatus (SSP) tendons.

LD Transfer Technique

Dissection of the LD tendon was performed to isolate it from the TM. After complete separation, the LD tendon was removed from its insertion on the humerus. Non-absorbable sutures (Ethibond No. 2, Ethicon Inc.) were then meticulously applied to both ends of the LD tendon, utilizing the Krackow suture technique. While applying traction to the sutures, we bluntly released the distal LD muscle to increase its excursion (Fig. 2A). After obtaining sufficient tendon length, with the patient's arm positioned in full IR and 45° abduction for proper tension adjustment, the harvested LD tendon was then securely attached to the proximal part of the LT using a transosseous technique with non-absorbable sutures (Ethibond No. 2, Ethicon Inc.) (Fig. 2B). Three transosseous sutures were employed to complete the attachment. To enhance the repair, additional stabilization was provided using 2 knotless anchors (4.5-mm PushLock, Arthrex). The 4 suture strands from the LD tendon were fixed into the first PushLock anchor, while the remaining 3 strands from the proximal, middle, and distal transosseous sutures were secured in the second PushLock anchor. In cases of concurrent ISP cuff tears, they were also repaired in a transosseous fashion during the same procedure.

Combined LDTM Tendon Transfer

Following the initial surgical approach, the combined LDTM tendons were concurrently detached from its insertion without distinguishing between the individual tendons. Subsequently, both edges of the harvested LDTM tendons were clasped using a pair of forceps. Thereafter, non-absorbable sutures (Ethibond No. 2, Ethicon Inc.) were meticulously applied to the tendons in a Krackow stitching pattern (Fig. 3A). During the tensioning of the sutures, the LDTM muscles' surrounding adhesions were carefully released to enhance their mobility and reach. The patient's arm was positioned in full IR and at a 45° abduction angle with the appropriate tension. A single medial triple-loaded suture anchor (4.5-mm PEEK Corkscrew FT, Arthrex Inc.) was then placed about 2 cm below the GT, adjacent to the lateral aspect of the bicipital groove. Utilizing a 16-G spinal needle, 6 sutures from this medial anchor were passed through, situated 2–3 cm medially from

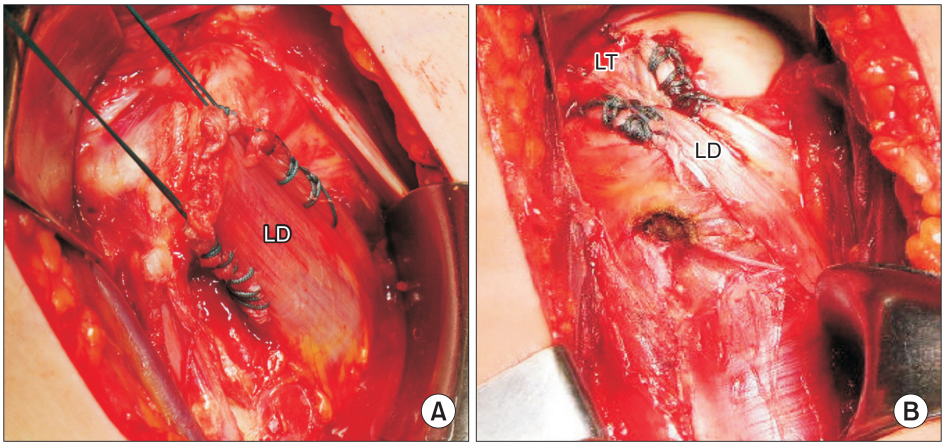

Fig. 2. (A) After dissecting the latissimus dorsi (LD) tendon separated from the teres major tendon, the LD was detached from its insertion at the humerus. Then, the tendon was sutured in a Krackow stitch pattern. Traction was applied to these sutures while the distal portion of the LD muscle was bluntly released to enhance the excursion. (B) Once an adequate length of the tendon was obtained, it was attached to the lesser tuberosity (LT).

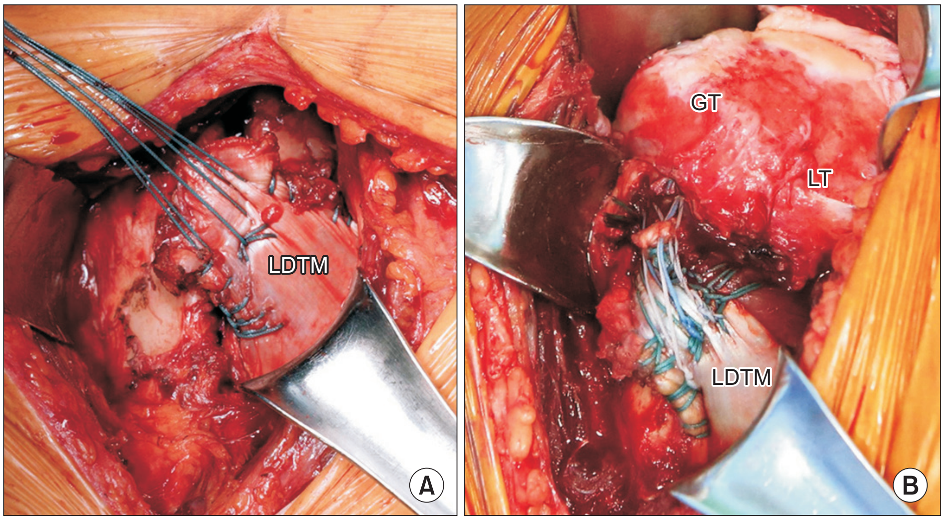

Fig. 3. (A) The combined latissimus dorsi and teres major (LDTM) tendons were concurrently detached from the humerus, without individual tendon separation. Krackow stitching was applied to the LDTM tendons. (B) Following thorough dissection and release from the adjacent connective tissues, the LDTM tendons were affixed distally at the lateral margin of the greater tuberosity (GT) and just laterally to the biceps groove. LT: lesser tuberosity.

the harvested tendon's edge, with each suture pair meticulously tied. Subsequently, the combined LDTM tendon was affixed just below the GT's lateral border and lateral to the biceps groove, employing 3 lateral anchors (4.75-mm SwiveLock, Arthrex Inc.) with the suture bridge method, instead of the upper part of the LT as documented in previous studies (Fig. 3B).[9,13)] The placement of the tendon slightly below the GT altered the vector to a less vertical orientation, enhancing tendon tautness. This strategic positioning not only averted potential impingement on the axillary nerve but also achieved the intended tensioning of the transferred tendon (Fig. 4).

Postoperative Management

Patients wore an abduction brace set in an internally rotated position for 8 weeks postoperatively. Throughout this phase, the patients were restricted to engaging only in passive ROM exercises, which were conducted using a continuous passive motion apparatus. After the initial 8 weeks, they discontinued the brace and began active-assisted ROM exercises. For the next 3 months, patients were advised to avoid heavy lifting and bearing body weight, aiding the tendon-to-bone healing. Following this, unrestricted full internal and external rotation (ER) was permitted, with subsequent initiation of strength training exercises focused on deltoid and scapular stabilization. Depending on preoperative activity levels, engagement in sports was allowed at 6 months postoperatively.

Clinical Assessment

Clinical evaluations encompassed data collection on patients' age, sex, osteoporosis status, body mass index (BMI), smoking habits, dominant arm, and medical comorbidities. Additionally, we evaluated and recorded both preoperative and postoperative pain levels using the visual analog scale, the Single Assessment Numeric Evaluation, University of California Los Angeles Shoulder Score, American Shoulder and Elbow Surgeons (ASES) score,

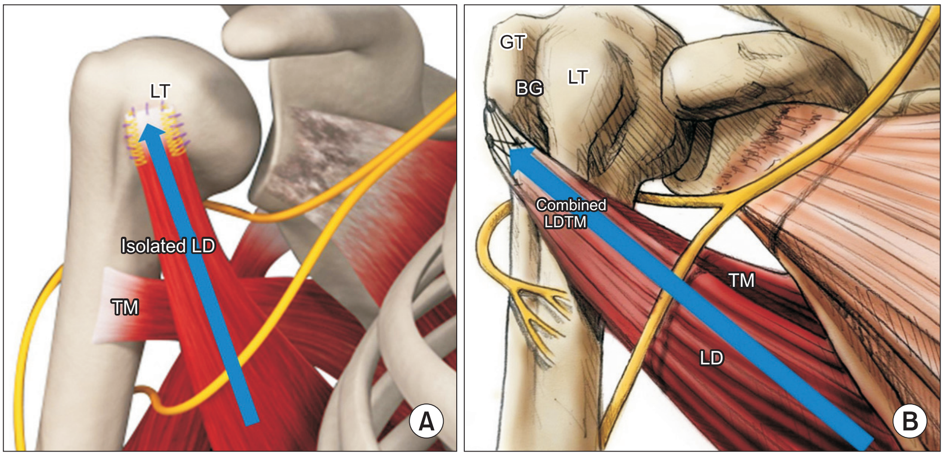

Fig. 4 The isolated latissimus dorsi (LD) tendon transfer affixed to the upper portion of the lesser tuberosity (LT) (A) and the combined latissimus dorsi and teres major (TM) tendon transfer secured to the greater tuberosity (GT) (B). Altering the attachment point to the GT modifies the trajectory of the transferred tendon (represented by a blue arrow) to a less vertical orientation, thereby enhancing tendon tautness. This modification not only mitigates the risk of axillary nerve entrapment between the remnant subscapularis muscle portion and upper portion of the teres major tendon, but also effectively increases the tension in the transferred combined latissimus dorsi and teres major (LDTM) tendon. BG: biceps groove. Adapted from Baek et al., with permission of Elsevier.[14)]

and activities of daily living that require active internal rotation (ADLIR).[16,17)] Evaluations of the shoulder encompassed forward flexion (FF) in the scapular plane, external arm rotation at 0° abduction, external arm rotation at 90° abduction, and IR. IR was quantified by the highest reachable level with the thumb. A research coordinator in the outpatient department conducted all clinical scoring and measured active ROM (aROM). Furthermore, for the objective evaluation of the strength of the shoulder ROM, we utilized a hand-held dynamometer (Hoggan Health Industries) for preoperative and postoperative measurements. The primary outcome was the assessment of IR strength, while secondary outcomes included other clinical scores, aROM, and IR-related clinical scores and functional outcomes. A single senior shoulder surgeon (CHB) assessed the SSC-specific examinations, including the belly-press, bear-hug, and lift-off tests at both pre-and 2-year follow-ups. The belly-press test is positive when, with arm at the side and elbow bent 90°, the patient shows IR weakness or compensates by extending the elbow or shoulder while pressing the palm against the abdomen.[18)] A positive bear-hug test is determined when the patient, with the palm of the involved side placed on the opposite shoulder and elbow anterior to the body, cannot maintain the position against an externally applied rotation force to the forearm.[19)] A lift-off test is positive if a patient with a hand on the mid-lumbar spine fails to lift the hand by internally rotating the arm or compensates by extending the elbow or shoulder.[20)] Evaluations were conducted to determine the achievement of the minimal clinically important difference (MCID) and the patient-acceptable symptomatic state (PASS), utilizing established criteria for rotator cuff repair.[21)]

Radiologic Assessment

Radiologic assessments included true anteroposterior (AP), lateral scapular, and axillary lateral imaging conducted both before and after surgery for all shoulders. True AP views were captured with patients standing in a neutral arm position. For the evaluation of anterior glenohumeral subluxation, we utilized the axillary lateral view, which is characterized by identifying an anterior displacement of the humeral head's center relative to the midpoint of the glenoid (Fig. 5).[14,22)] At the final follow-up, a reduction in anterior glenohumeral subluxation was noted, reflecting the repositioning of the humeral head from its previously subluxated state. Measurements of acromiohumeral distance (AHD) and assessment of the Hamada classification were conducted using the true AP view, in accordance with established methodologies.[23,24)] Two raters (JGK and SJK) established the reliability of AHD measurements and Hamada classification. A preoperative MRI examination was conducted on the affected shoulder for all patients. The Goutallier grading system was employed to estimate the FI grade of the rotator cuff muscles from sagittal oblique images (the Y-view). During the final follow-up, MRI was conducted to evaluate the condition of the transferred tendon. This tendon's status was categorized into 1

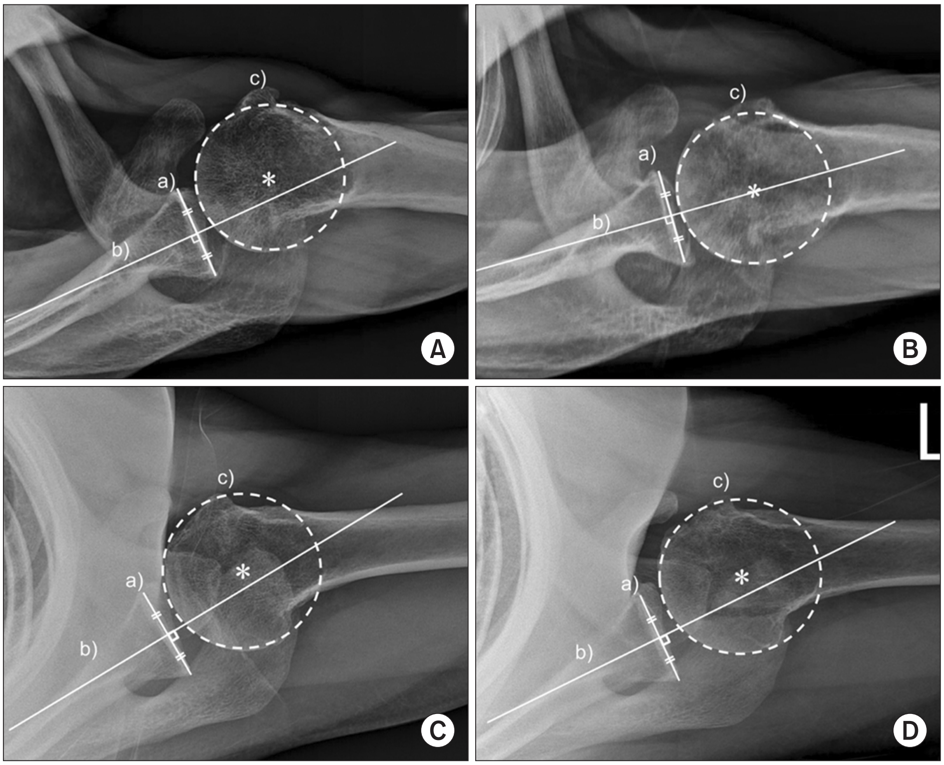

Fig. 5. Preoperative and 2-year follow-up examination. Axillary lateral radiographic findings illustrate the restoration of anterior subluxation of the humeral head (asterisk) following the combined latissimus dorsi and teres major transfer (A, preoperative; B, postoperative). In contrast, in the case of the latissimus dorsi transfer, the final follow-up radiographs show that the preoperative anterior subluxation has not been successfully restored (C, preoperative; D, postoperative). a) A line segment passing through the articular surface of the glenoid. b) A line segment perpendicular to line segment a), bisecting it at the midpoint of the glenoid. c) A circle that includes a portion of the articular surface of the humerus as its arc. *The center of the circle c).

of 5 levels, following the classification system devised by Sugaya et al.,25) with Types IV and V considered tears. An experienced board-certified musculoskeletal radiologist (SHY) with a decade of experience, blinded to the study's outcomes, interpreted the MRI results.

Statistical Analysis

A power analysis was carried out to ensure that our study was adequately powered to detect the observed differences in IR strength using G*Power software (version 3.1.9; Heinrich Heine University), with an α level of 0.05 and statistical power of 0.9. The required sample size was calculated to be at least 22 participants per group. The interobserver reliability of AHD and Hamada grade assessments between 2 different evaluators (JGK and SJK) was evaluated using the intraclass correlation coefficient (ICC) for the radiographic data. Preoperative and follow-up clinical and imaging results were analyzed with the paired *t*-test Wilcoxon signed-rank test for continuous variables and McNemar's test for categorical variables. Clinical and radiological outcomes were compared between the 2 surgical techniques using the nonparametric Student *t*-test or the Mann-Whitney *U*-test, and the chi-square or Fisher's exact test for continuous and categorical data, respectively. Statistical evaluations were conducted via SPSS software for Windows version 25.0 (IBM Corp.), with the significance level set at 95%.

RESULTS

The study cohort included 29 male participants (13 and 16 in the LD and LDTM groups, respectively) and 24 female participants (10 and 14 in the LD and LDTM groups, respectively). The average age at the time of operation was 63.7 ± 6.3 years and 65.2 ± 5.4 years for the LD and LDTM groups, respectively (Table 1). There were no significant differences in demographics, comorbid conditions, such as diabetes mellitus and hypertension, BMI, or the degree of fatty degeneration in the rotator cuff musculature (Table 1). Moreover, 19 individuals (82.6%) and 28 individuals (93.3%) in the LD and LDTM groups ($p = 0.222$), respectively, attained an improvement in the ASES score, marked by an MCID of 11.1, as established for rotator cuff repairs.21) Furthermore, 11 patients (47.8%) and 17 patients (56.7%) in the LD and LDTM groups ($p = 0.523$), respectively, reached the PASS with an ASES score elevation of 86.7 points, aligning with the benchmarks for rotator cuff repair efficacy. While both groups demonstrated a significant improvement in pain scores and clinical scores, the ADLIR score was significantly higher in the LDTM group (Table 2). An improvement in all active ROMs was observable postoperatively in both groups, except for active ER

Table 1. Demographic Characteristics of Study Participants

Variable	LD group (n = 23)	LDTM group (n = 30)	*p*-value
Sex (male:female)	13 (56.5):10 (43.4)	16 (53.3):14 (46.6)	0.821
Age (yr)	63.7 ± 6.3 (54–73)	65.2 ± 5.4 (57–81)	0.361
Dominant arm involvement	20 (86.9)	25 (83.3)	0.721
BMI (kg/m^2)	25.0 ± 2.7	24.1 ± 1.9	0.155
HTN	14 (60.8)	11 (36.6)	0.083
DM	4 (17.3)	7 (23.3)	0.605
Smoking	2 (8.6)	3 (10.0)	0.875
Symptom duration (mo)	9.6 ± 2.2	9.9 ± 2.4	0.623
Prior rotator cuff repair surgery	2 (8.7)	5 (16.6)	0.405
Preoperative anterior glenohumeral subluxation	9 (39.1)	15 (50.0)	0.431
Preoperative Hamada Grade			0.605
Grade 1	19 (82.6)	23 (76.6)	
Grade 2	4 (17.3)	7 (23.3)	
Preoperative SSC FI grade			0.670
Grade 3	9 (39.1)	10 (33.3)	
Grade 4	14 (60.8)	20 (66.6)	
Preoperative SSP FI grade			0.760
Grade 3	17 (73.9)	21 (70.0)	
Grade 4	6 (26.0)	9 (30.0)	
Preoperative ISP FI grade			0.686
Grade 0 or 1	18 (78.2)	22 (73.3)	
Grade 2	5 (21.7)	8 (26.6)	
Preoperative Tm FI grade			0.606
Grade 0 or 1	21 (91.3)	26 (86.6)	
Grade 2	2 (8.6)	4 (13.3)	
Reparable concomitant ISP tear*	4 (17.3)	8 (26.6)	0.424
Biceps tenotomy*	3 (13.0)	7 (23.3)	0.484
Biceps soft-tissue tenodesis*	5 (21.7)	6 (20.0)	1.000

Values are presented as number (%), mean ± SD (range), or mean ± SD.
LD: latissimus dorsi transfer, LDTM: latissimus dorsi and teres major transfer, BMI: body mass index, HTN: hypertension, DM: diabetes mellitus, SSC: subscapularis, FI: fatty infiltration, SSP: supraspinatus, ISP: infraspinatus, Tm: teres minor, SD: standard deviation.
*During surgery.

ROM. We observed a trend toward a slight increase in ER at the side and 90° abduction postoperatively in group LD, whereas a slight decrease was noted in the LDTM group, but this did not reach statistical significance. In terms of strength assessment, the improvement of the FF, IR, and ER strength was confirmed postoperatively in both groups. Notably, the IR strength at side and 90° abduction showed a significant postoperative increase in the LDTM group compared to that in the LD group (Table 3). The positive ratio of SSC-specific physical examination significantly decreased postoperatively in both groups; however, a significant decrease in the LDTM group was confirmed at the 2-year follow-up examination (belly-press test, $p = 0.027$; bear-hug test, $p = 0.031$; and lift-off test, $p = 0.032$) (Table 3). The interobserver reliabilities for measuring preoperative and postoperative AHD ($\text{ICC}_{\text{pre-AHD}} = 0.96$ [95% confidence interval, 0.93–0.97], $p < 0.001$; $\text{ICC}_{\text{post-AHD}} = 0.94$ [0.91–0.96], $p < 0.001$) as well as preoperative and postoperative Hamada grade ($\text{ICC}_{\text{pre-Hamada}} = 0.90$ [0.82–0.94], $p < 0.001$; $\text{ICC}_{\text{post-Hamada}} = 0.94$ [0.90–0.97], $p < 0.001$) were excellent. Slightly decreased AHD (LD group,

Table 2. Comparison of Clinical and Radiologic Outcomes between the Groups

Variable	LD group (n = 23)	LDTM group (n = 30)	*p*-value
VAS pain score			
Preoperative	4.7 ± 1.4	4.9 ± 1.0	0.904
Postoperative	1.4 ± 0.8	1.4 ± 0.7	0.821
p-value	< 0.001	< 0.001	
Constant score			
Preoperative	48.8 ± 5.6	48.1 ± 6.1	0.661
Postoperative	68.9 ± 3.4	70.4 ± 6.6	0.313
p-value	< 0.001	< 0.001	
ASES score			
Preoperative	49.9 ± 10.7	47.5 ± 7.2	0.326
Postoperative	77.7 ± 13.0	82.2 ± 9.0	0.123
p-value	< 0.001	< 0.001	
UCLA Shoulder Score			
Preoperative	19.3 ± 3.0	19.9 ± 5.1	0.574
Postoperative	27.5 ± 2.9	28.9 ± 2.4	0.076
p-value	< 0.001	< 0.001	
ADLIR score			
Preoperative	13.4 ± 5.2	14.3 ± 3.1	0.452
Postoperative	24.1 ± 4.2	26.6 ± 4.0	0.017
p-value	< 0.001	< 0.001	
Active ROM (°)			
FE (°)			
Preoperative	124 ± 19	120 ± 17	0.494
Postoperative	155 ± 11	157 ± 10	0.764
p-value	< 0.001	< 0.001	
ABD (°)			
Preoperative	93 ± 18	96 ± 16	0.583
Postoperative	130 ± 13	132 ± 13	0.615
p-value	< 0.001	< 0.001	
ER at 90° ABD (°)			
Preoperative	62 ± 11	61 ± 11	0.711
Postoperative	66 ± 13	59 ± 12	0.056
p-value	0.185	0.592	
ER at side (°)			
Preoperative	51 ± 9	52 ± 10	0.824
Postoperative	57 ± 16	49 ± 11	0.078
p-value	0.171	0.256	
IR at back*			
Preoperative	3.9 ± 2.5	4.0 ± 2.6	0.824
Postoperative	6.6 ± 1.5	7.4 ± 1.6	0.078
p-value	< 0.001	< 0.001	
AHD (mm)			
Preoperative	8.3 ± 1.8	8.1 ± 2.0	0.711
Postoperative	8.0 ± 2.0	7.7 ± 1.5	0.539
p-value	0.243	0.111	
Hamada grade			
Preoperative	1.3 ± 0.4	1.3 ± 0.4	0.518
Postoperative	1.5 ± 0.5	1.4 ± 0.5	0.974
p-value	0.110	0.423	

Values are presented as mean ± standard deviation.
LD: latissimus dorsi transfer, LDTM: latissimus dorsi and teres major transfer, VAS: visual analog scale, ASES: American Shoulder and Elbow Surgeons, UCLA: University of California Los Angeles, ADLIR: activities of daily living that require active internal rotation, ROM: range of motion, FE: forward elevation, ABD: abduction, ER: external rotation, IR: internal rotation, AHD: acromiohumeral distance.
*Internal rotation was measured as the level that could be reached by the thumb; 0, greater trochanter; 2, buttock; 4, lumbosacral junction; 6, L3; 8, T12; and 10, T7.

Table 3. Comparison of Strength and Subscapularis-specific Examinations Outcomes between the Groups

Variable	LD group (n = 23)	LDTM group (n = 30)	*p*-value
Strength (N)			
FE			
Preoperative	12.5 ± 3.1	11.3 ± 2.5	0.151
Postoperative	29.3 ± 7.2	32.5 ± 6.0	0.131
p-value	< 0.001	< 0.001	
IR at side			
Preoperative	11.3 ± 3.2	10.6 ± 1.7	0.628
Postoperative	24.7 ± 3.0	27.7 ± 2.8	< 0.001
p-value	< 0.001	< 0.001	
ER at 90° ABD			
Preoperative	17.3 ± 4.1	18.9 ± 2.4	0.080
Postoperative	18.0 ± 4.8	19.5 ± 2.8	0.268
p-value	0.216	0.236	
ER at side			
Preoperative	21.1 ± 5.4	20.5 ± 4.7	0.652
Postoperative	21.7 ± 5.6	21.2 ± 4.6	0.603
p-value	0.402	0.263	
Subscapularis-specific examinations			
Belly-press (positive %)			
Preoperative	87.0	90.0	0.729
Postoperative	34.8	10.0	0.027
p-value	< 0.001	< 0.001	
Bear-hug (positive %)			
Preoperative	91.3	90.0	0.640
Postoperative	39.1	13.3	0.031
p-value	< 0.001	< 0.001	
Lift-off (positive %)			
Preoperative	95.7	93.3	0.717
Postoperative	43.5	16.7	0.032
p-value	< 0.001	< 0.001	

Values are presented as mean ± standard deviation.
LD: latissimus dorsi transfer, LDTM: latissimus dorsi and teres major transfer, FE: forward elevation, IR: internal rotation, ER: external rotation.

$p = 0.243$; LDTM group, $p = 0.111$) and increased Hamada grade (LD group, $p = 0.110$; LDTM group, $p = 0.423$) were found between the preoperative and 2-year follow-up examination findings in both groups, but no statistical significance was observed (Table 2). The restoration rate of anterior glenohumeral subluxation before and after

Fig. 6. T2-weighted oblique axial-view magnetic resonance imaging demonstrating intact integrity of the transferred latissimus dorsi (LD) (A) and combined latissimus dorsi and teres major (LDTM) tendons (B), indicating difference in thickness of each transferred tendon. Arrow: isolated LD (A), combined LDTM (B).

surgery was observed to decrease from 39.1% to 26.1% in the LD group ($p = 0.250$), while in the LDTM group, a significant reduction was noted from 50.0% preoperatively to 3.3% postoperatively ($p < 0.001$). At the 2-year follow-up, a statistically significantly lower rate of anterior subluxation was confirmed in the LDTM group compared to the LD group (26.1% vs. 3.3%, $p = 0.015$) (Fig. 5).

Complications

Early postoperative superficial infections occurred in 1 patient from each group, which were effectively treated with open debridement and intravenous antibiotics. After LD transfer, 1 patient experienced temporary axillary nerve palsy, which was resolved after 3 months. Additionally, postoperative MRI findings revealed no retearing of the transferred LD tendon (Fig. 6). Following the combined LDTM transfer, no nerve-related complications, regarding radial or axillary nerve injuries, were reported. MRI analysis revealed that 1 patient (3.3%) experienced non-retracted partial retears at the musculotendinous junction of the transferred LDTM tendon. Conservative treatment with a shoulder abduction brace for 4 weeks led to complete recovery.

DISCUSSION

To our knowledge, this is the first comparative clinical study between LD and combined LDTM transfer for IASRCTs. The primary finding is that while both transfers improved pain, overall clinical scores, and active ROM postoperatively, combined LDTM transfer attached to the GT was superior to LD transfer attached to the LT in terms of IR strength and SSC-specific examinations. Radiologically, neither group showed a significant progression in cuff tear arthropathy (Hamada grade) or decreased AHD at the 2-year follow-up period; however, a higher reduction in preoperative anterior glenohumeral subluxation was noted in the combined LDTM transfer group.

IASRCTs present significant clinical challenges, characterized by concurrent tears in the SSC and SSP. These tears result in considerable functional impairments, notably the loss of active shoulder elevation and IR. Although the optimal treatment strategy is still debated, recent focus has shifted to the promising outcomes of LD and combined LDTM transfer, succeeding the traditional PM transfer. This study was conducted to compare these transfers and evaluate their clinical and radiological efficacy.

In this study, both groups showed improvements in pain and overall clinical scores. However, although no differences were observed between the 2 groups in overall clinical scores and active ROM, a distinction was evident in IR strength, ADLIR score, and the positive ratio of SSC-specific examination. This discrepancy may arise from the following advantages of LDTM attached to the GT regarding the IR strength. Even considering that the following previous studies pertained primarily to patients with irreparable posterosuperior cuff tears, Boileau et al.[26] noted that an isolated LD tendon is prone to tearing owing to its thin nature. They suggested that a combined transfer of LD and TM tendons could offer better manageability and securement during the transfer process. Additionally, patients with diminished ER experienced a more pronounced improvement in ER when undergoing combined LD and TM tendon transfer, as opposed to an isolated LD transfer.[27,28] Lichtenberg et al.[29] further established that patients receiving a combined LDTM transfer exhibited substantially enhanced abduction strength postoperatively in comparison with an isolated LD transfer.

Moreover, Baek et al.[30] conducted a cadaveric biomechanical study, which compared LD transfer to combined LDTM transfer, both attached to GT for IASRCTs. Their findings revealed that both LDTM and LD transfers resulted in a significant increase in internal resting rotation when compared to the IASRCT condition and the intact rotator cuff state, particularly notable at abduction angles of 30° ($p < 0.006$) and 60° ($p < 0.013$). Notably, the LDTM transfer significantly outperformed the LD transfer in increasing internal resting rotation. Additionally, Werthel et al.12) undertook a biomechanical study on the attachment site of tendon transfers for LD, TM, and PM in cases of irreparable SSC tendon tears. Their findings indicated that attaching the LD and TM tendon transfers to the SSP footprint yielded greater IR moment arms compared to attachments at the SSC footprint.

In cases of LDTM transfer, we reattached the combined LDTM tendon distally to the lateral aspect of the GT and just laterally to the biceps groove. This reattachment position, just distal to the humerus, rendered the tendon's vector less vertical and enhanced its tensioning. This approach effectively mitigated the risk of axillary nerve impingement between the upper part of the TM muscle and the inferior part of the SSC muscle, a concern raised by Elhassan et al.,13) while simultaneously allowing for an enhancement in tendon tensioning effect.

Consequently, it is presumed that the biomechanical advantages derived from the combined strength of muscles, the attachment site for the IR moment arm, and the tendon tensioning effect contributed to the differences observed in IR strength outcomes and SSC-specific examination between LD and combined LDTM transfer in this clinical study. However, it should be considered whether the observed increase in IR strength and the reduced positive ratio in SSC-specific examinations in the LDTM group are effects of the combined transfer or are due to tendon tensioning influenced by the attachment site. This necessitates further investigation through a well-structured prospective trial to control for confounding factors.

In the IASRCTs setting, it is important to consider anterior decentralization of the humeral head. At the final 2-year follow-up examination, a difference was observed in the rate of anterior subluxation between both groups. This difference is attributed to the combined effect of the TM on the LD. The strengthened combined LD and TM tendon transfer plays a role as a depressor of the humerus and compliments the forces with posterior rotator cuff muscles, notably ISP and Tm, thus rebalancing the force couple and creating a dynamic joint-centering effect. Moreover, the TM tendon contributes to this stabilizing effect with scapulohumeral kinematics, aligning in its movements with the SSC tendon. Halder et al.'s biomechanical study31) found that LD transfer alters its function from depressing the humeral head to compressing the glenoid at increased abduction angles, in contrast to the TM tendon, which consistently induces humeral head depression due to its scapular attachment. Mulla et al.'s computational study32) demonstrated consistent stability ratios across the humeral elevation range for rotator cuff and TM tendons. They also found that the LD and TM tendons function as superior stabilizers and joint compressors. As a result, the combined transfer of LD and TM tendons generates a significant axial force couple, enhancing joint compressive force and inferior stability.32,33) We conjectured that this combined transfer, particularly with a posterior line of pull similar to that of the SSC and influenced by the TM tendon's scapulohumeral kinematics, is effective in reducing anterior glenohumeral subluxation.

Meanwhile, no significant pre- and postoperative changes were observed in AHD and Hamada grades, while no differences between the 2 groups were identified. Both procedures, albeit short term, act as restraints to superior translation of the humeral head. However, as aforementioned, the TM tendon has biomechanical advantages in terms of its scapulothoracic rhythm and joint compressive effect. Moreover, Baek et al.,34) in their biomechanical comparative study between isolated LD and combined LDTM transfer, although it must be taken into account that the attachment location is GT rather than LT, also reported that isolated LD transfer is less effective in preventing superior translation compared to combined LDTM. Therefore, although no differences were observed in the short term, the impact of degenerative changes over time on the effectiveness of LDTM in influencing the superior translation of the humeral head with the progression of osteoarthritis warrants further midterm and long-term follow-up examinations.

The study has some limitations. First, its retrospective nature and the limited number of participants may have limited its validity in clinical practice. Additionally, the study's observations were based on short term 2-year results. Furthermore, there was a variation in the study duration for each group. LD transfers attached to LT were conducted from 2013 to 2015, while from 2016 to June 2021, the preference shifted to combined LDTM transfers attached to GT owing to their perceived clinical and biomechanical benefits. However, as both transfers were employed in managing same preoperative condition in patients, no significant differences in demographic information were observed between the 2 groups prior to surgery. Second, it should be taken into account that the difference between the 2 surgical procedures is not simply due to whether LD alone or combined LDTM is applied. Limitations of different attachment sites, types of anchors used, and anchoring techniques used must be recognized.

Therefore, these factors may represent limitations of the study by introducing bias that affects the results. Consequently, further well-planned research involving subjects carefully selected to minimize the potential for bias induction is deemed necessary. Another limitation lies in the subjective nature of the SSC-specific physical examination. The SSC-specific examinations were conducted by a single experienced shoulder surgeon at the outpatient clinic. Unlike radiological assessments, physical examinations require direct contact with the patient, which may present limitations when performed by multiple practitioners or at different times. However, due to the surgeon's decades of expertise, the physical examination's reliability is considered reasonably assured. Furthermore, the technique used to assess anterior subluxation through axillary lateral view radiography also presents challenges, particularly in consistently positioning the arm parallel to the scapula. Finally, the study results might have been biased owing to additional procedures, such as long head of the biceps tenotomy/tenodesis and ISP tendon repair.

In conclusion, while both LD and combined LDTM transfer improved postoperative pain relief, clinical scores, and active ROM postoperatively, the combined LDTM transfer attached to GT was superior to LD transfer attached to LT in terms of IR strength, as well as related ADLIR score and SSC-specific examinations. Neither group showed significant progress in cuff tear arthropathy or decreased AHD at 2-year follow-up; however, the combined LDTM transfer notably improved preoperative anterior glenohumeral subluxation.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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