JSES International 7 (2023) 35–43

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Long-term outcomes of teres major transfer for irreparable posterosuperior rotator cuff tears in patients aged <65 years

Andrea Celli, MD*, Chiara Paroni, MD, Pierluigi Bonucci, MD, Luigi Celli, MD, Prof

Shoulder and Elbow Unit, Department of Orthopaedic Surgery, Hesperia Hospital, Modena, Italy

ARTICLE INFO

Keywords:
Rotator cuff tears
Irreparable rotator cuff tears
Muscle-tendon transfer
Teres major muscle transfer
Local tendon transfer
Regional tendon transfer
Glenohumeral joint degenerative change
Long-term follow-up

Level of evidence: Level IV; Case Series; Treatment Study

Background: Massive rotator cuff tears are defined as irreparable when tendon-to-bone or tendon-to-tendon continuity with the adducted arm cannot be restored and severe muscle fatty infiltration is present. Tendon transfer is a palliative procedure that improves shoulder function and relieves pain.

Methods: We reviewed the records of patients aged <65 years, whose irreparable posterosuperior rotator cuff tears had been managed with teres major tendon transfer at our institution. Their 5- and 10-year clinical and radiographic follow-up records were examined to assess long-term outcomes. Patients' Constant Score, Disabilities of the Arm, Shoulder, and Hand score, and the visual analog scale for pain were calculated before the procedure and at 5 and 10 years.

Results: There were 24 consecutive patients aged <65 years (mean, 59; 12 men and 12 women) who had received no prior treatment except rehabilitation. All patients underwent teres major tendon transfer due to the failure of conservative treatment. The mean Constant Score was 26 preoperatively and 68 and 66 at 5 and 10 years, respectively ($P = .0001$ and $P = .25$). The mean Disabilities of the Arm, Shoulder, and Hand scores were 62.2 preoperatively and 7.8 and 9.3 at 5 and 10 years, respectively ($P = .0009$ and $P = .1$). The mean visual analog scale scores at rest were 6.1 preoperatively, and 0.3 and 0.5 at 5 and 10 years, respectively ($P = .0003$ and $P = .1$). Based on Hamada's classification, at 5 years, 3 patients showed grade 2 changes, and another had grade 3 changes; at 10 years, 7 patients showed grade 2 changes, and one showed grade 3 changes. Complications (8%) developed after the 10-year evaluation and included pain in 1 patient and secondary rupture of the transfer in another.

Discussion: Improving shoulder function and reducing pain in relatively young patients with irreparable posterosuperior cuff tears involves replacing the lost muscle with a muscle-tendon transfer. The chief aims of the procedure are to restore the balance with the subscapularis muscle, achieve joint stability, keep the humeral head in the glenoid cavity, and improve shoulder abduction and external rotation. Teres major tendon transfer can achieve these goals. Altogether, 22 of our 24 patients experienced improved daily activity function and pain relief that became stable after 5 years. Teres major transfers are useful surgical procedures, particularly in younger patients and in those with high functional demands, providing good and stable long-term results.

Massive rotator cuff tears are considered irreparable when tendon-to-bone or tendon-to-tendon continuity with the arm in adduction cannot be restored, and the lesion is concomitant with the loss or degeneration of tendon tissue or with muscle atrophy[26] with fatty degeneration and tendon retraction.

The clinical implications of this type of lesion include impairment or loss of active movement and variable and often persistent pain that limits daily living activities.

Patients often ask for pain mitigation and restoration of essential daily activity functions. In some cases, examination after injection of a local anesthetic into the subacromial space allows to determine whether an acceptable level of daily activity function can be restored with a rehabilitation program. Such patients are amenable to conservative treatment or to the less demanding surgical techniques, such as débridement associated with subacromial bursectomy and long head of biceps tenotomy,[37,47] partial

Institutional review board approval was not required for this study.

*Corresponding author: Andrea Celli, MD, Via Emilia Est 380\1 Modena 41124, Italy.

E-mail address: celli.andrea.md@gmail.com (A. Celli).

https://doi.org/10.1016/j.jseint.2022.08.020

Table I
Preoperative evaluation: Constant Score (CS), Disabilities of the Arm, Shoulder, and Hand (DASH) score, visual analog scale (VAS) at rest and during motion, and Hamada grade.

Case	Gender	Side	Age (y)	Constant Score	Abduction (degrees)	Flexion (degrees)	External rotation adduction (degrees)	External rotation abduction (degrees)	DASH score	VAS at rest	VAS on movement	Hamada grade
1	M	R	48	17	45	45	0	0	60	6	8	1
2	F	R	61	23	80	110	0	0	60.8	5	9	1
3	M	R	65	33	110	130	20	50	62.5	7	8	1
4	M	R	51	31	75	110	0	40	68.3	4	8	1
5	F	R	61	35	100	110	0	60	64.2	6	9	1
6	M	L	58	24	75	75	0	50	75.8	8	8	1
7	F	R	62	20	70	70	10	0	75.8	7	9	1
8	F	R	65	20	70	70	0	30	70	7	8	1
9	M	R	63	20	80	80	0	20	67.5	8	8	1
10	M	R	62	30	80	80	20	0	44.2	4	7	1
11	F	R	61	33	100	100	0	10	53.3	6	8	1
12	M	R	64	29	120	90	10	20	56.7	6	7	1
13	M	R	53	34	90	90	40	50	50.8	4	6	1
14	M	R	65	31	90	110	0	30	48.3	6	7	1
15	F	R	61	28	60	60	10	30	68.3	5	6	1
16	F	L	62	26	110	90	0	60	58.3	8	8	1
17	F	R	64	32	45	75	30	40	61.7	4	6	1
18	M	R	65	24	90	90	20	50	61.7	8	8	1
19	M	R	61	23	40	60	20	60	65.8	6	7	1
20	F	R	43	27	0	90	20	60	70.8	6	8	1
21	F	L	65	24	60	90	10	50	65.8	8	9	1
22	M	L	62	33	110	90	20	50	62.5	5	7	1
23	F	R	59	23	50	50	10	60	60.8	6	7	1
24	F	R	50	22	90	90	30	30	60.8	8	8	1

M, male; *F*, female; *R*, right; *L*, left.

Figure 1 The patient, under general anesthesia, is placed in beach chair position with the trunk angled 60°-70° from the horizontal position.

cuff repair,[37,47,48] tendon transfer,[6,10–14,23,24] and joint replacement.[55] Elderly patients with rotator cuff lesions and degenerative glenohumeral arthropathy can often be managed by reverse total shoulder arthroplasty,[55] a procedure that is not recommended for younger subjects with higher functional demands. Younger patients with irreparable posterosuperior rotator cuff tears who complain of pain and functional impairment but do not suffer from glenohumeral arthropathy may benefit from tendon transfer using the teres major, latissimus dorsi, or the lower portion of the trapezius.[10,11,23,24]

We hypothesize that in patients aged <65 years, massive irreparable posterosuperior rotator cuff tears can be repaired with teres major muscle-tendon transfer, which can restore motor function (in particular, abduction, external rotation, and stability), stabilize the shoulder, and slow down the progression of degenerative joint arthritis.

This retrospective study was undertaken to evaluate the 5-year and 10-year clinical and radiographic records of 24 such patients (12 men and 12 women), who underwent teres major tendon transfer at our institution after a failed conservative treatment.

Materials and methods

Patient demographics

Inclusion criteria were age <65 years at the time of the transfer and no prior shoulder surgery. Indications for muscle transfer were posterosuperior rotator cuff tears with infraspinatus and supraspinatus fatty degeneration[26] but without cuff tear arthropathy or degenerative joint disease[29] and a well-preserved subscapularis muscle, including the upper portion.

Exclusion criteria were shoulder instability, rotator cuff surgery, shoulder joint fracture, glenohumeral osteoarthritis, rheumatoid arthritis, poor motivation, general comorbidities, and psychiatric illness.

These criteria allowed identifying 24 consecutive patients, 12 men and 12 women, who underwent teres major tendon transfer at our institution from 1998 to 2008 (Table I). Their mean age at the time of surgery was 59 years (range 43-65). The dominant arm was involved in 21 cases.

The study was performed in accordance with the 1964 Declaration of Helsinki Ethical Standards, as updated in 2004.

All patients reported being unable to perform daily living activities due to pain and loss of shoulder function. According to the clinical records, all patients had received a local anesthetic injection into the subacromial space and had subsequently followed a rehabilitation program that had improved their clinical condition but had provided inadequate pain relief and daily activity function. They all had a preserved passive range of motion (ROM) compared with the contralateral side and intact subscapularis and teres minor tendons and reduced acromion-humeral distance (6 mm, Hamada grade 1)[29]; however, fatty degeneration of the muscles[26] associated with tendon retraction[45] prevented the restoration of tendon-to-bone or tendon-to-tendon continuity with the arm adducted.

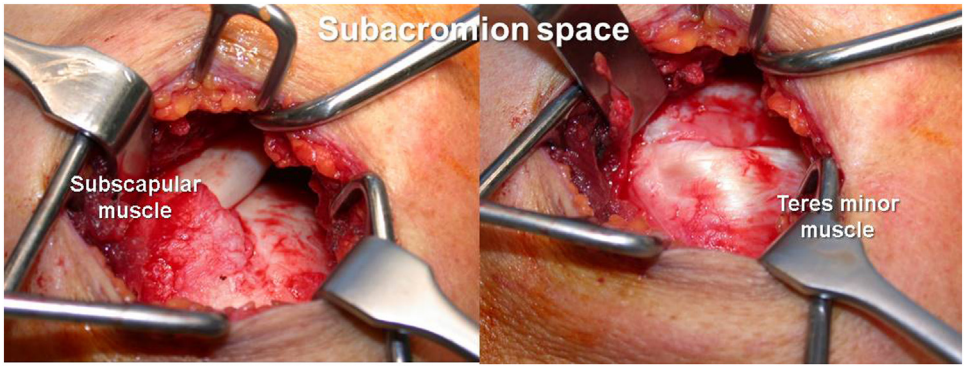

Figure 2 In patients with irreparable posterosuperior lesion with tendon retraction and muscle atrophy but without joint degenerative changes, a posterior skin incision running above the posterior pillar of the armpit is added to the acromion incision.

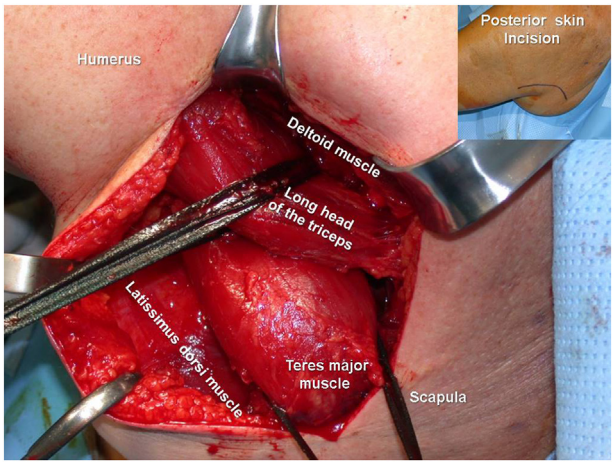

Figure 3 The posterior skin incision is curved and runs above the posterior pillar of the armpit, from the external margin of the scapula to the upper third of the humerus; the posterior border of the deltoid, the long head of the triceps, and the teres major are identified. The teres major is isolated from its scapular origin to the humeral insertion and its tendon is divided from the latissimus dorsi tendon.

Patient evaluation

We evaluated the patients' clinical history and compared their preoperative and postoperative clinical status, including pain, ROM, and satisfaction, based on records collected at 5 and 10 years.

The diagnosis of massive irreparable posterosuperior rotator cuff tears was based on physical examination and x-ray, magnetic resonance imaging (MRI), and computed tomography scans.

Electromyography (EMG) was performed to exclude a peripheral nerve deficit.

The Constant Score (CS),[15,16] the Disabilities of the Arm, Shoulder, and Hand[28] score, and the visual analog scale[34] for pain at rest and during movement were obtained from the clinical records.

Radiographic evaluation

X-ray, MRI, and computed tomography scans were obtained before the procedure and at 5 and 10 years. All patients had grade 3 or 4 according to the Goutallier classification system[26] and grade 3 tendon retraction according to the Patte classification.[45] The irreparable nature of the tears was also evaluated intraoperatively before the tendon transfer.

Statistical analysis

Data are reported as mean ± standard deviation. The normal distribution of data was tested with Shapiro-Wilk's test and homoscedasticity with the F test for homogeneity of variances. Wilcoxon's signed-rank test was used to compare the variables between the 2 follow-up evaluations. A P value < .05 (2-tailed) was considered significant. Analyses were performed using STATA software package (2009, release 11; Stata Corp, College Station, TX, USA).

Surgical technique

In these patients, the teres major transfer was performed by the senior author (L.C.) according to the original open technique[11] from 1998 to 2008.

The patient under general anesthesia is placed in the beach chair position with the trunk at a 60°-70° angle from the horizontal position (Fig. 1).

The first step involves an anterior to posterior skin incision beginning on the anterior corner of the acromion and running for 5 cm along the lateral edge of the acromion.

The deltoid fibers are divided longitudinally between the anterior and middle portions to enable the acromioplasty and expose the subacromial space. All 24 patients underwent biceps tenotomy.

If the anterior subacromial exposure demonstrates supraspinatus and infraspinatus tendon retraction and muscle atrophy, which prevent tendon repair, but no degenerative joint alterations (Fig. 2), a curved skin incision is performed above the posterior pillar of the armpit, from the external margin of the scapula to the upper third of the humerus (Fig. 3).

The teres major is isolated from its scapular origin to its humeral insertion, and its tendon is divided from the latissimus dorsi tendon (Fig. 3).

At this time, the axillary nerve in the quadrilateral space and the radial nerve running under the teres' major tendon are identified and protected (Fig. 4).

With the arm in maximum internal rotation, to gain a clearer view of the humeral insertion of the teres major tendon, the tendon is detached from the humerus, sparing the latissimus dorsi insertion.

The muscle is mobilized by soft tissue dissection as close to the muscle origin as necessary to ensure adequate proximal migration.

Once the neurovascular pedicle has been isolated at the level of the medial third of the muscle (Fig. 5), tetanization allows evaluating maximum muscle contraction (Fig. 6). In these 24 patients,

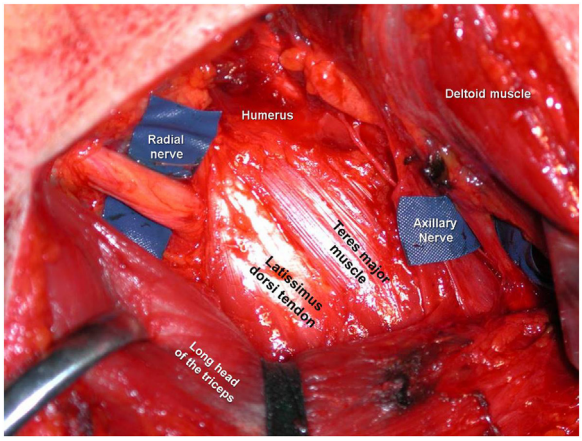

Figure 4 The axillary nerve in the quadrilateral space and the radial nerve under the teres major tendon are identified and protected.

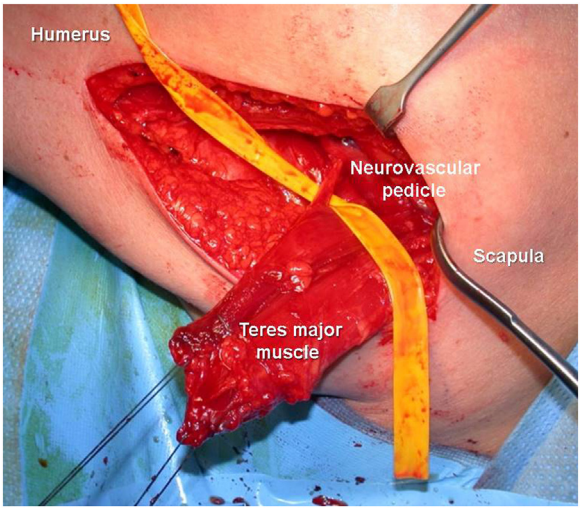

Figure 5 The neurovascular pedicle has been isolated at the level of the medial third of the muscle.

the mean fiber excursion from resting length to maximum contraction was 8 cm (range 6-11).

After the axillary nerve has been visualized and protected to avoid injury, the teres major and its pedicle are prepared, preserving the scapular insertion, and the tendon is brought to the subacromial space by passing it under the deltoid muscle using a long curved clamp.

The tendon is anchored to the bone in the infraspinatus area, in a position that is halfway between the resting length and the maximum contraction of the muscle. The tendon is fixed using transosseous nonabsorbable sutures according to the original technique (Figs. 7 and 8), with the arm in 40° of abduction and neutral rotation, to avoid excessive tension on the tendon when the arm is internally rotated. Where possible, the remaining portion of the cuff is attached to the tendon transfer (Fig. 9).

Postoperative management

The arm is placed in 45° of abduction and neutral rotation in an abduction splint. After 3 weeks, passive ROM exercises are begun, avoiding internal rotation. The splint is removed after 6 weeks. Active abduction and external rotation exercises similar to those performed for massive rotator cuff rehabilitation are begun, with progressive stretching and strengthening. Recovery usually takes 10-12 months.

Results

Patients were evaluated at a mean follow-up time of 64 months (60-75) and 125 months (120-144).

There were no perioperative infections, skin problems, or neurological or vascular complications. Axillary and radial nerve function was normal in all patients. Complications (8%) developed after the 10-year evaluation and included pain in one patient and secondary rupture of the transfer in another.

Range of motion

ROM improved significantly from the preoperative evaluation to the first follow-up ($P < .05$) and became stable between the first and second follow-up visits ($P > .05$). The improvements in active forward elevation, 90° shoulder abduction, and external rotation were substantially stable at the 2 follow-up evaluations (Tables II and III). Pain diminished and remained consistently low. A similar degree of patient satisfaction was recorded at both follow-up visits.

With regard to the mean arc of active motion, abduction increased from 76° (±27.69) to 143° (±29.21; $P = .0001$) at 5 years to 142° (±39.04; $P = .4$) at 10 years. Flexion rose from 85° (±20.55) to 150° (±24.42; $P = .0005$) at 5 years and to 152° (±26.42; $P = .3$) at 10 years. External rotation in adduction increased from 11° (±11.91) to 34° (±25.73; $P = .0003$) at 5 years to 39° (±28.69; $P = .26$) at 10 years. Active external rotation at 90° of abduction improved from 35° (±21.46) to 65° (±18.08; $P = .0004$) at 5 years and fell slightly to 62° (±21.62; $P = .30$) at 10 years.

Functional assessment

The preoperative values of the functional scores are reported in Table I, the 5-year values are reported in Table II, and the 10-year values are reported in Table III.

The mean CS was 26.75 (±5.27) before the procedure, 68.17 (±10.04) at 5 years ($P = .0001$), and 66.17 (±10.9; $P = .25$) at 10 years.

The mean Disabilities of the Arm, Shoulder, and Hand score was 62.28 (±7.85) before the procedure, 7.88 (±4.26; $P = .0009$) at the first follow-up evaluation, and 9.37 (±6.42; $P = .1$) at the second.

The mean visual analog scale score at rest was 6.1 preoperatively and 0.3 and 0.5 at 5 and 10 years, respectively ($P = .0003$ and $P = .1$). One patient (#21) did not achieve relief from pain.

Radiographic outcomes

At the first follow-up, the MRI scans depicted a secondary rupture of the tendon transfer from its insertion on the great tuberosity (case #16). This was the only patient who also had fatty degeneration in the transfer.

The x-rays taken before the procedure and at 5 and 10 years allowed assessing the evolution of secondary degenerative changes of the glenohumeral joint. Based on Hamada's classification, at the first follow-up, 3 patients showed grade 2 changes and showed grade 3 changes (case #16). At the second follow-up, 7 patients had grade 2 changes, and patient #16 still had grade 3 changes.

At the 10-year follow-up visit, patients also underwent dynamic ultrasonography and EMG, which allowed to determine the contraction capacity acquired by the teres major transfer in

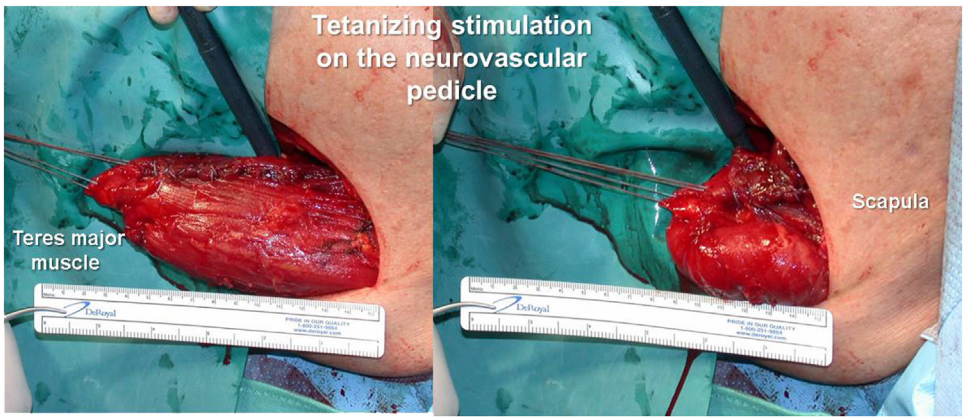

Figure 6 Tetanization of the neurovascular pedicle allowed evaluating maximum muscle contraction.

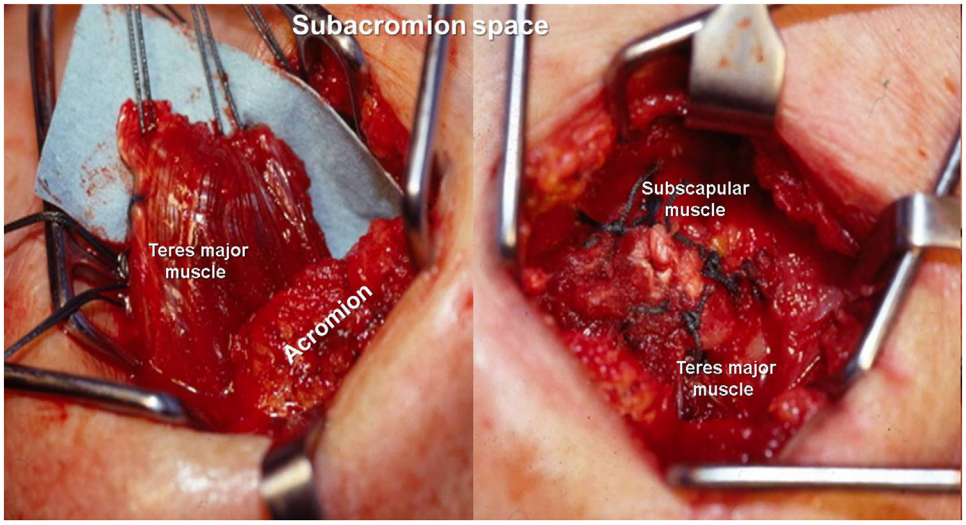

Figure 7 The tendon transfer is brought to the subacromial space by passing it under the deltoid muscle using a long curved clamp and anchored to bone in the infraspinatus area with 2 nonabsorbable sutures.

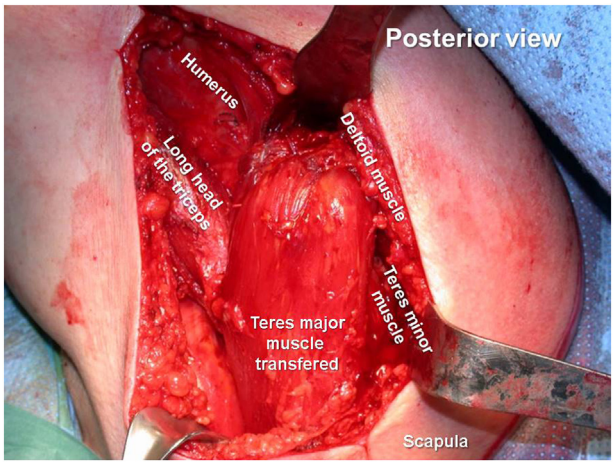

Figure 8 Posterior view of the teres major transferred into the subacromial space.

external rotation. We were able to document that in 23 of the 24 patients, the reduced but preserved internal rotation was however synergistic with the activity of the latissimus dorsi muscle, also in resisted movements. The remaining patient (case #16) was the one who had experienced failure of the tendon transfer due to secondary rupture, which prevented EMG analysis during shoulder motion.

Discussion

Surgical repair of massive posterosuperior rotator cuff tears fails in 21%-91% of cases.[2,4,33,36] The failure rates of revision surgery are even higher.[44,50] Lesions typically recur in the first year after primary fixation[4,32,37] due to atrophy with irreversible fatty degeneration and retraction of the torn muscles.

Conservative treatment for 6 months should always be attempted before considering surgery because it can increase the arc of motion and relieve pain. The aims of rehabilitation are overall strengthening of the deltoid and periscapular muscles[1,13,38]; if this treatment does not provide sufficient improvement, the success rate of further nonoperative management declines and surgery may be considered.

An irreparable posterosuperior rotator cuff tear can be salvaged by surgical treatment if the patient does not suffer from degenerative joint changes or tendon retraction.

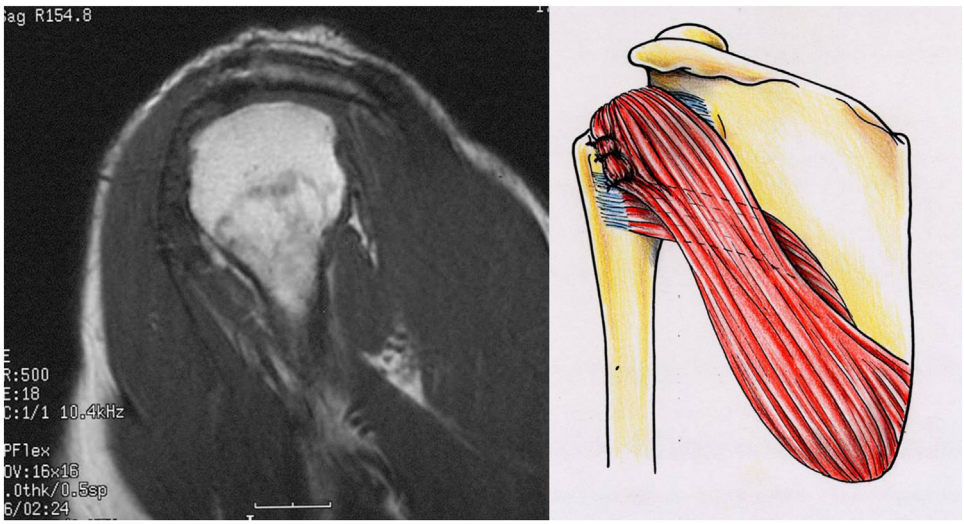

Figure 9 MRI scan of the teres major transfer. *MRI*, magnetic resonance imaging.

Table II
Postoperative evaluation at 5-year follow-up: Constant Score (CS), Disabilities of the Arm, Shoulder, and Hand (DASH) score, visual analog scale (VAS) at rest and during motion, and Hamada grade.

Case	F-U (mo)	Constant Score	Abduction (degrees)	Flexion (degrees)	External rotation adduction (degrees)	External rotation abduction (degrees)	DASH score	VAS at rest	VAS at movements	Hamada grade	Patient's satisfaction
1	60	62	110	110	40	40	12.5	0	1	1	Yes
2	61	73	170	170	0	60	6.7	0	1	1	Yes
3	63	66	160	160	30	80	12.5	2	3	2	Yes
4	62	76	160	160	10	70	3.3	0	0	1	Yes
5	64	79	170	160	25	80	3.3	0	0	1	Yes
6	61	77	150	170	10	70	5	0	1	1	Yes
7	60	63	120	150	20	30	2.5	0	0	1	Yes
8	70	70	130	150	55	75	7.5	0	2	2	Yes
9	60	75	140	160	20	70	5.8	0	0	1	Yes
10	61	61	100	120	20	40	9.2	0	2	1	Yes
11	63	72	170	170	40	70	8.3	0	1	1	Yes
12	66	76	150	140	0	20	5	0	0	1	Yes
13	68	69	170	170	50	90	3.3	0	0	1	Yes
14	60	74	160	170	0	70	5	0	1	1	Yes
15	64	50	80	120	20	50	14.2	0	3	1	Yes
16	61	35	110	110	0	80	20	4	6	3	No
17	68	59	135	135	40	70	10	0	1	1	Yes
18	70	69	160	160	30	75	5.8	0	0	1	Yes
19	71	69	80	90	50	80	6.7	0	1	1	Yes
20	69	78	170	170	70	85	4.2	0	0	1	Yes
21	73	72	160	160	70	70	9.2	0	1	1	Yes
22	75	62	150	150	60	50	13.3	3	5	1	Yes
23	61	72	160	180	80	60	10	0	2	2	Yes
24	64	77	180	180	80	80	5.8	0	0	1	Yes

One surgical option is tenotomy of the long head of biceps with/without partial cuff repair. Its aims are to repair the rotator cuff tendon, which can be sutured back to the tuberosities without excessive tension, and to address any causes of pain or factors threatening the repair. A partial repair tries to restore the force couples and the "suspension bridge" and to prevent secondary extension of the tear.[7,9] Superior cuff repair with a fascia lata autograft,[41] a dermal allograft patch,[8] or a long head of biceps transplant[5] can prevent the superior migration of the humeral head and restore the shoulder force couples. Denard et al[17] have reported an increase in shoulder motion and a 55% failure rate in a series of 59 patients treated with a dermal allograft with a follow-up of at least 12 months. An alternative procedure involves implanting a balloon-shaped biodegradable spacer between the acromion and the humeral head. The spacer is designed to create a physical barrier between the tissues in the subacromial space and keep the humeral head depressed in patients with an insufficient rotator cuff to facilitate deltoid action.[18] The failure risk of this salvage technique is related to patient activities and age.

Another method to restore shoulder function and reduce pain in relatively young patients involves replacing the lost muscle with a muscle-tendon transfer.

Steindler[52] argued that any upper limb muscle could be transferred to serve a different function because "movements, not muscles are represented in the cerebral cortex." If the transfer allows to recover muscle strength and the range, amount, and direction of tendon sliding, a muscle transfer can function like the muscle that is being replaced. If the injured muscle cannot be repaired, a muscle-tendon unit transfer has the potential to restore the lost motor function, either specific movements and joint

Table III
Postoperative evaluation at 10-year follow-up: Constant Score (CS), Disabilities of the Arm, Shoulder, and Hand (DASH) score, visual analog scale (VAS) at rest and during motion, and Hamada grade.

Case	F-U (mo)	Constant Score	Abduction (degrees)	Flexion (degrees)	External rotation adduction (degrees)	External rotation abduction (degrees)	DASH score	VAS at rest	VAS on movements	Hamada grade	Patient's satisfaction
1	124	59	110	110	40	40	12.5	2	3	2	Yes
2	121	69	170	170	0	60	7.5	0	0	1	Yes
3	124	64	160	160	30	80	13.3	2	3	2	Yes
4	130	71	110	110	10	70	5	0	0	1	Yes
5	120	76	180	180	80	80	5.8	0	1	1	Yes
6	123	72	150	170	10	70	5.8	0	2	1	Yes
7	144	63	120	150	20	30	3.3	0	0	1	Yes
8	123	70	130	150	55	75	7.5	0	2	2	Yes
9	122	75	140	160	20	70	5.8	0	0	1	Yes
10	130	69	180	180	80	80	6.7	0	0	1	Yes
11	126	72	170	170	40	70	8.3	0	0	1	Yes
12	120	68	150	140	0	20	8.3	0	2	1	Yes
13	123	69	170	170	50	90	6.7	0	1	1	Yes
14	128	69	160	170	0	70	9.2	0	0	1	Yes
15	132	58	80	120	20	50	14.2	0	2	2	Yes
16	120	21	0	70	0	0	35.8	5	6	3	No
17	127	67	160	160	80	80	5	0	0	1	Yes
18	125	69	160	160	30	75	5	0	1	1	Yes
19	130	65	130	150	35	60	10.8	0	2	2	Yes
20	120	74	170	170	70	85	5.8	0	0	1	Yes
21	122	68	150	150	70	70	10	3	4	1	Yes
22	125	56	150	150	60	50	14.2	0	1	2	Yes
23	120	72	160	180	80	60	10.8	0	1	2	Yes
24	124	72	160	160	60	60	7.5	0	0	1	Yes

stability. In shoulder surgery, we distinguish local from regional tendon transfers.

Local tendon transfers are actually rotation flaps raised from the intact tendons of the cuff, usually the subscapularis or the teres minor.[43] They are simple to prepare and allow covering the humeral head with innervated and vascularized tissue while restoring continuity with the residual cuff tendons.[43] However, they involve the risk of a worse functional status compared with before the procedure, particularly where the functions that rely on subscapularis and teres minor muscle-tendon unit integrity are concerned.

Regional tendon transfers are collected from the thoracic scapulohumeral region and can replace one or more cuff muscles.[10–12,23,42,46,53,55] A variety of regional tendon transfers can be used for irreparable posterosuperior massive cuffs: latissimus dorsi, teres major, and the lower portion of the trapezius. In 1976, Beevor[3] wrote, “the brain only knows function, not individual muscle action.” In irreparable rotator cuff tears, good results can be obtained with regional tendon transfers, provided that the surgeon performs a meticulous operative technique and has a good understanding of the biomechanical principles involved.

Selection of the suitable muscle must is based on the excursion and synergism of the transfer and the contraction and strength of the antagonist muscles.[10,11] Moreover, if the tendon transfer crosses 2 joints in succession, its resultant force vector exerts an effect on each joint in proportion to the moment arm of each axis. Replacing the infraspinatus muscle in patients with posterosuperior lesions requires considering the resultant force vector close to the infraspinatus muscle.

Latissimus dorsi transfer was originally described by Gerber in 1988[24] to restore humeral head depression and external rotation in young, active patients without glenohumeral arthritis or significant static migration of the humeral head. These indications are similar to those of teres major transfer. The procedure essentially restores posterior muscle strength. At 10-year follow-up, Gerber was able to document the durability of the reconstruction, with good to excellent outcomes and preserved functional scores, including CS.[25] Complications include stiffness, traumatic failure of the transfer, nerve dysesthesia, and failure of the deltoid reattachment.[25] El-Azab et al reported similar results with a long-term failure rate of 10% and a conversion rate to reverse shoulder arthroplasty of 4%.[19] We had a similar complication rate (8%), with transfer failure and severe pain.

Lower trapezius tendon transfer has recently been described to manage irreparable posterosuperior rotator cuff tears.[20,21] Elhassan et al[22] followed 32 patients for at least 2 years and found that the better outcomes correlated with preoperative status, but a longer follow-up is clearly required to compare outcomes.

We have been performing teres major transfer based on the consideration that the resultant force vector of the transfer acting on the glenohumeral joint can be altered by scapulohumeral movements, but not by scapulothoracic movements; this entails a scapulohumeral muscle such as the infraspinatus or the teres major is required.

The teres major arises from the dorsal border of the inferior angle of the scapula. It is physiologically and biomechanically similar to the posterosuperior rotator cuff muscles. The line of action of a teres major transfer in relation to the glenoid is similar to that of the infraspinatus.[6,27,39]

The length of the neurovascular pedicle of the teres major is sufficient for suturing to the greater tuberosity.[27] Intraoperative stimulation allows to determine its adequate tension and anchoring site on the tuberosity, which should be halfway between maximum contraction to resting length. We also believe that teres major transfer can restore the couple force vectors with the subscapularis muscle, restoring scapulohumeral joint stability and active motion in abduction and external rotation, as described in the recent literature.[6,10,11,30,40,51] This anatomical aspect of the teres major has also been assessed by Henseler et al,[30] who demonstrated that it is physiologically closer to the infraspinatus muscle. Although the teres major is relatively short and thick, it is however sufficiently long and can provide a transfer with a suitable amount of tension and contractility.[31]

We believe that the evaluation of muscle excursion by intraoperative stimulation of the neurovascular pedicle is important to establish the correct anchoring point of the tendon on the humerus.

In particular, finding the midpoint between maximum muscle extension and contraction allows defining the average excursion, which has always been used to establish transplant tension and its more or less anterior site on the humerus. We consider this step a critical factor for the success of the transfer because it reduces the risk of excessive tensioning of the transfer, particularly of secondary failure, as reported by Kany et al.[35]

The second critical factor affecting the risk of secondary rupture is that the teres major is a scapulohumeral muscle and that during shoulder motions, it remains in the same position, tension, and direction as the teres minor and the infraspinatus, unlike the latissimus dorsi, which is a thoracohumeral muscle.

Our patients experienced a significant improvement in active abduction and its stabilization over the 2 follow-up visits. A similar improvement has already been described in other works, which show that this muscle transfer is suitable to restore shoulder motion.[6,10,11,30,40,51,54]

All our patients but 2 (cases #16 and # 21) achieved relief from pain, which became stable over time.

In addition, daily activity function improved in 23 of the 24 patients, who were satisfied with their outcome. The last patient (case #16) achieved relief from pain but not active shoulder function and was not satisfied with her outcome. Comparison of her preoperative and postoperative x-rays documented a severe superior migration of her humeral head, which demonstrates that the teres major tendon transfer had insufficient strength to depress the humeral head and was unable to restore the balance with the subscapularis muscle and to reduce the risk of evolution to cuff tear arthropathy.

The electrical activity of the tendon transfer, documented by EMG, was maximal in external rotation, particularly in 90° of abduction, which explains the greater improvements of 23 of 24 patients in external rotation and abduction than in adduction, as also reported in the literature.[6,10,11,30,40,51] Electrical activity was also documented in resisted internal rotation and in the synergistic movements that recruit the latissimus dorsi. This confirms Steindler's view[52] that when a muscle is transferred, the mind can alter the activity of the muscle, which greatly contributes to the effect of rehabilitation.

A comparison of the preoperative values to those of the 2 follow-up time points highlighted significant differences at 5 years, whereas functional improvement and pain relief between 5 and 10 years were not significantly different since the gains had become stable.

Altogether, the teres major muscle has useful anatomical and biomechanical features that enable its use as a muscle transfer in patients with irreparable posterosuperior rotator cuff tears. The direction of the resultant vector contraction force of the transfer is similar to the resultant force vector of the infraspinatus and teres minor muscles; in addition, the transfer has sufficient relative strength and contraction length to replace the torn muscle.[10,11,54]

Biomechanically, the teres major is a scapulohumeral muscle like the infraspinatus, and the resultant force is not altered by the scapulothoracic movements during shoulder abduction.

The length of the muscle-tendon unit is sufficient for insertion into the greater tuberosity.[14,54] The fixation site in the infraspinatus area depends on the excursion length of the muscle, which can be established by intraoperative stimulation. The transfer restores the balance with the upper portion of the subscapularis muscle.

The neurovascular pedicle is sufficiently long to be transposed, usually at the medial third of the muscle.[49]

After teres major transfer, scapular lateral rotation gradually increased, whereas this has not been reported after latissimus dorsi transfer.[31] Greater scapular lateral rotation after teres major transfer indicates a glenohumeral rotation to achieve the final position of the shoulder joint, considering that humeral abduction is the result of scapulothoracic and glenohumeral motion.[31] The teres major transfer, which becomes a scapulohumeral muscle, has a moment arm around the glenohumeral center of rotation.[31] Therefore, the teres major is physiologically more similar to the infraspinatus muscle.

Using the approach described previously, the procedure does not present major technical difficulties. Two steps require special attention: the teres major tendon should be detached close to the humeral shaft and the radial and axillary nerves should carefully be protected.

The main disadvantages of using the teres major include the shortness and thickness of the tendon and the fact that the suture needs to be done on the muscle fibers.

Tensioning of the transfer is challenging. The suture on the greater tuberosity must ensure passive internal rotation, whereas excessive tensioning induces a tenodesis effect on the muscle.

Conclusion

Teres major transfer is a salvage procedure for irreparable posterosuperior rotator cuff tears, restoring motion, providing pain relief, and reducing the risk of evolution to cuff tear arthropathy. In our experience, it can achieve good long-term results. Patient selection, an accurate surgical technique and adequate rehabilitation are all critical for success.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Ainsworth R. Physiotherapy rehabilitation in patients with massive, irreparable rotator cuff tears. Musculoskelet Care 2006;4:140-51. https://doi.org/10.1002/msc.85.
2. Bartl C, Kouloumentas P, Holzapfel K, Eichhorn S, Wortler K, Imhoff A, et al. Long-term outcome and structural integrity following open repair of massive rotator cuff tears. Int J Shoulder Surg 2012;6:1-8. https://doi.org/10.4103/0973-6042.94304.
3. Beevor A. Quoted by boyes. J Hand Surg 1976;1:83.
4. Bigliani LU, Cordasco FA, Mcllveen SJ. Musso ES: operative repair of massive rotator cuff tears: long-term results. J Shoulder Elbow Surg 1992;1:20-30.
5. Boutsiadis A, Chen S, Jiang C, Lenoir H, Delsol P, Barth J. Long head of the biceps as a suitable available local tissue autograft for superior capsular reconstruction: "The Chinese Way". Arthrosc Tech 2017;6:e1559-66. https://doi.org/10.1016/j.eats.2017.06.030.
6. Buijze GA, Keereweer S, Jennings G, Vorster W, Debeer J. Musculotendinous transfer as a treatment option for irreparable posterosuperior rotator cuff tears: teres major or latissimus dorsi? Clin Anat 2007;20:919-23. https://doi.org/10.1002/ca.20547.
7. Burkhart SS. Reconciling the paradox of rotator cuff repair versus debridement: a unified biomechanical rationale for the treatment of rotator cuff tears. Arthroscopy 1994;10:4-19.
8. Burkhart SS, Denard PJ, Adams CR, Brady PC, Hartzler RU. Arthroscopic superior capsular reconstruction for massive irreparable rotator cuff repair. Arthrosc Tech 2016;5:e1407-18. https://doi.org/10.1016/j.eats.2016.08.024.
9. Burkhart SS, Esch JC, Jolson RS. The rotator crescent and rotator cable: an anatomic description of the shoulder's "suspension bridge". Arthroscopy 1993;9:611-6.
10. Celli A, Marongiu MC, Rovesta C, Celli L. Transplant of the teres major in the treatment of irreparable injuries of the rotator cuff (long-term analysis of results). Chir Organi Mov 2005;90:121-32.
11. Celli L, Rovesta C, Marongiu MC, Manzieri S. Transplantation of teres major muscle for infraspinatus muscle in irreparabile rotator cuff tears. J Shoulder Elbow Surg 1998;7:485-90.
12. Cofield RH. Subscapular muscle transposition for repair of chronic rotator cuff tears. Surg Gynecol Obstet 1982;154:667-72.

13. Collin PG, Gain S, Nguyen Huu F, Lädermann A. Is rehabilitation effective in massive rotator cuff tears? Orthop Traumatol Surg Res 2015;101(suppl):S203-5. https://doi.org/10.1016/j.otsr.2015.03.001.
14. Combes JM, Mansat M. In: L'epaule de Bonnel F, Blotman F, Mansat M, editors. Lambeau du muscle grand rond dans les ruptures massives de la coiffe des rotateurs. Etude expérimentale. Springer-Verlag: Springer, Paris; 1993. p. 318-30.
15. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop 1987;214:160-4.
16. Constant CR. Constant score technique for shoulder function SECEC information. January 1991 n.3 pag 26-29.
17. Denard PJ, Brady PC, Adams CR, Tokish JM, Burkhart SS. Preliminary results of arthroscopic superior capsule reconstruction with dermal allograft. Arthroscopy 2018;34:93-9. https://doi.org/10.1016/j.arthro.2017.08.265.
18. Deranlot J, Herisson O, Nourissat G, Zbili D, Werthel JD, Vigan M, et al. Arthroscopic subacromial spacer implantation in patients with massive irreparable rotator cuff tears: clinical and radiographic results of 39 retrospectives cases. Arthroscopy 2017;33:1639-44. https://doi.org/10.1016/j.arthro.2017.03.029.
19. El-Azab HM, Rott O, Irlenbusch U. Long-term follow-up after latissimus dorsi transfer for irreparable posterosuperior rotator cuff tears. J Bone Joint Surg Am 2015;18:462-9. https://doi.org/10.2106/JBJS.M.00235.
20. Elhassan B. Technique of tendon transfers about the shoulder in patients with brachial plexus injury. JBJS Essent Surg Tech 2012;2:e19.1-2. https://doi.org/10.1302/2058-5241.1.000003.
21. Elhassan B, Bishop AT, Hartzler RU, Shin AY, Spinner RJ. Tendon transfer options about the shoulder in patients with brachial plexus injury. J Bone Joint Surg Am 2012;94-A:1391-8. https://doi.org/10.2106/JBJS.J.01913.
22. Elhassan B, Wagner E, Werthel JD. Outcome of lower trapezius transfer to reconstruct massive irreparable posterior-superior rotator cuff tear. J Shoulder Elbow Surg 2016;25:1346-53. https://doi.org/10.1016/j.jse.2015.12.006.
23. Gerber C, Vinh TS, Hertel R, Hess CW. Latissimus dorsi transfer for the treatment of massive tears of the rotator cuff. A preliminary report. Clin Orthop 1988;232:51-61.
24. Gerber C. Latissiumus dorsi transfer for the treatment of irreparable tears of the rotator cuff. Clin Orthop 1992;275:52-160.
25. Gerber C, Rahm SA, Catanzaro S, Farshad M, Moor BK. Latissimus dorsi tendon transfer for treatment of irreparable posterosuperior rotator cuff tears: long-term results at a minimum follow-up of ten years. J Bone Joint Surg Am 2013;95-A:1920-6. https://doi.org/10.2106/JBJS.M.00122.
26. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures : pre- and postoperative evaluation by CT scan. Clin Orthop 1994;304:78-83.
27. de Groot JH, van de Sande MA, Meskers CG, Rozing PM. Pathological teres major activation in patients with massive rotator cuff tears alters with pain relief and/ or salvage surgery transfer. Clin Biomech (Bristol, Avon) 2006;21(Suppl 1):S27-32. https://doi.org/10.1016/j.clinbiomech.2005.09.011.
28. Gummesson C, Ward M, Atroshi I. The shortened disabilities of the arm, shoulder and hand questionnaire (Quick DASH): validity and reliability based on responses within the full-length DASH. BMC Musculoskelet Disord 2006;7:2-3. https://doi.org/10.1186/1471-2474-7-44.
29. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears: a long-term observation. Clin Orthop Relat Res 1990;254:92-6.
30. Henseler JF, Nagels J, van der Zwaal P, Nelissen RG. Teres major tendon transfer for patients with massive irreparable posterosuperior rotator cuff tears: short-term clinical results. Bone Joint J 2013;95-B:523-9. https://doi.org/10.1302/0301-620X.95B4.30390.
31. Henseler JF, Kolk A, Zondag B, Nagels J, de Groot JH, Nelissen RGHH. Three-dimensional shoulder motion after teres major or latissimus dorsi tendon transfer for posterosuperior rotator cuff tears. J Shoulder Elbow Surg 2017;26:1955-63. https://doi.org/10.1016/j.jse.2017.03.023.
32. Iannotti JP, Deutsch A, Green A, Rudicel S, Christensen J, Marraffino S, et al. Time to failure after rotator cuff repair: a prospective imaging study. J Bone Joint Surg Am 2013;95-A:965-71. https://doi.org/10.2106/JBJS.L.00708.
33. Jo CH, Shin JS, Lee YG, Shin WH, Kim H, Lee SY, et al. Platelet-rich plasma for arthroscopic repair of large tomassive rotator cuff tears: a randomized, single-blind, parallel-group trial. Am J Sports Med 2013;41:2240-8. https://doi.org/10.1177/0363546513497925.
34. Johnson E. Visual analog scale (VAS). Am J Phys Med Rehabil 2001;80:717.
35. Kany J, Sekaran P, Grimberg J. Risk of latissimus dorsi tendon rupture after arthroscopic transfer for posterior superior rotator cuff tear: a comparative analysis of 3 humeral head fixation techniques. J Shoulder Elbow Surg 2020;29:282-90. https://doi.org/10.1016/j.jse.2019.06.019.
36. Kim SJ, Kim SH, Lee SK, Seo JW, Chun YM. Arthroscopic repair of massive contracted rotator cuff tears: aggressive release with anterior and posterior interval slides do not improve cuff healing and integrity. J Bone Joint Surg Am 2013;95-A:1482-8. https://doi.org/10.2106/JBJS.L.01193.
37. Koh KH, Laddha MS, Lim TK, Park JH, Yoo JC. Serial structural and functional assessments of rotator cuff repairs: do they differ at 6 and 19 months post-operatively? J Shoulder Elbow Surg 2012;21:859-66. https://doi.org/10.1016/j.jse.2011.05.027.
38. Levy O, Mullett H, Roberts S, Copeland S. The role of anterior deltoid reeducation in patients with massive irreparable degenerative rotator cuff tears. J Shoulder Elbow Surg 2008;17:863-70. https://doi.org/10.1016/j.jse.2008.04.005.
39. Magermans DJ, Chadwick EK, Veeger HE, van der Helm FC, Rozing PM. Biomechanical analysis of tendon transfers for massive rotator cuff tears. Clin Biomech (Bristol, Avon) 2004;19:350-7. https://doi.org/10.1016/j.clinbiomech.2003.11.013.
40. Mansat P, Dotziz A, Bellumore Y, Mansat M. Teres major flap: surgical anatomy, technique of harvesting, methods of fixation, postoperative management. In: Valenti P, editor. Tendon transfer for irreparable rotator cuff tear. Paris: Springer-Verlag France; 2011. p. 49-64. https://doi.org/10.1007/978-2-8178-0049-3.
41. Mihata T, Lee TQ, Watanabe C, Fukunishi K, Ohue M, Tsujimura T, et al. Clinical results of arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. Arthroscopy 2013;29:459-70. https://doi.org/10.1016/j.arthro.2012.10.022.
42. Mikasa M. Trapezius transfer for global tear of the rotator cuff. In: Bateman JE, Welsh RP, editors. Surgery of the shoulder. St Louis: CV Mosby; 1988. p. 196.
43. Neviaser RJ, Neviaser TJ. Transfer of subscapularis and teres minor for massive defects of the rotator cuff. In: Shoulder surgery. Berlin: Springer-Verlag; 1982. p. 60-9.
44. Parnes N, DeFranco M, Wells JH, Higgins LD, Warner JJ. Complications after arthroscopic revision rotator cuff repair. Arthroscopy 2013;29:1479-86. https://doi.org/10.1016/j.arthro.2013.06.015.
45. Patte D. Classification of rotator cuff lesions. Clin Orthop Relat Res 1990:81-6.
46. Resch H, Pavocz P, Ritter E, Matschi W. Transfer of the pectoralis major muscle for the treatment of the irreparable rupture of the subscapularis tendon. J Bone Joint Surg 2000;82-A:116-26.
47. Rockwood CA, Burkhead WZ. Management of patients with massive rotator cuff defects by acromioplasty and rotator cuff debridement. Orthop Trans 1988:12-190.
48. Rockwood CA Jr, Williams GR Jr, Burkhead WZ. Debridement of degenerative irreparable lesions of the rotator cuff. J Bone Joint Surg 1995;77-A:857-66.
49. Schoierer O, Herzberg G, Berthonnaud E, Dimnet J, Aswad R, Morin A. Anatomical basis of latissimus dorsi and teres major transfer in rotator cuff tear surgery with particular reference to the neurovascular pedicles. Surg Radiol Anat 2001;23:75-80.
50. Shamsudin A, Lam PH, Peters K, Rubenis I, Hackett L, Murrell GAC. Revision versus primary arthroscopic rotator cuff repair: a 2-year analysis of outcomes in 360 patients. Am J Sports Med 2015;43:557-64. https://doi.org/10.1177/0363546514560729.
51. Steenbrink F, Nelissen RG, Meskers CG, J van de Sande MA, Rozing PM, de Groot JH. Teres major muscle activation relates to clinical outcome in tendon transfer surgery. Clin Biomech (Bristol, Avon) 2010;25:187-93. https://doi.org/10.1016/j.clinbiomech.2009.11.001.
52. Steindler A. Tendon transplantation in the upper extremity. Am J Surg 1939;44:260.
53. Takagishi N. The new operation for the massive rotator cuff rupture. J Jap Orthop Assocc 1978;52:775-80.
54. Wang AA, Strauch RJ, Flatow EL, Bigliani LU, Rosenwasser MP. The teres major muscle: an anatomic study of its use as a tendon transfer. J Shoulder Elbow Surg 1999;8:334-8.
55. Warner JJP, Gerber C. Massive tears of the posterosuperior rotator cuff. In: Warner JJP, Iannotti JP, Gerber C, editors. Complex and revision problems in shoulder surgery. Philadelphia: Lippincott-Raven; 1997. p. 177-201.