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JSES International

journal homepage: www.jseinternational.org

Feasibility of lower trapezius and rhomboid minor transfer for irreparable subscapularis tears: an anatomic cadaveric study

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ARTICLE INFO

Keywords:

Lower trapezius
Rhomboid minor
Subscapularis
Tear
Irreparable
Transfer

Level of evidence: Anatomy Study; Cadaver Dissection

Background: Previously reported outcomes after tendon transfers to reconstruct the subscapularis are unpredictable and often unsatisfactory, especially in the presence of anterior humeral head subluxation. We studied the anatomic feasibility of the lower trapezius and the rhomboid minor transfer to reconstruct irreparable tendon tears of the subscapularis. The aim of this study was to determine the feasibility of lower trapezius and rhomboid minor transfer to reconstruct irreparable subscapularis tendon tears.

Materials and methods: We measured the tendons dimensions, muscles excursions, distances to pedicles, and dissection needed to complete a successful lower trapezius and/or rhomboid minor transfer to the subscapularis footprint in 10 cadaveric shoulders. The transferred muscles were detached distally, augmented with a semitendinosus and gracilis autograft, and passed anteriorly between the scapula and the subscapularis remnant through a small serratus window to reach the lesser tuberosity. The risk of pedicle compression was subjectively assessed in all cases.

Results: The trapezius and rhomboid tendons were asymmetric with an average length of 37.6 mm and 21.7 mm, an average width of 63 mm and 33.4 mm, respectively. The mean distances from each distal insertion to the lesser tuberosity were 109 mm for the trapezius and 144 mm for the rhomboid. Mean distances from tendon to pedicle were 57.9 mm and 33.1 mm, respectively. The mean size of the necessary serratus window was 49.4 mm, which was measured at maximal excursion achieved at maximal external rotation 90° representing two digitations. All of the tendon transfers were feasible, and the risk of pedicle compression was 20% for the trapezius and 10% for the rhomboid. Superior migration of the transfer was observed during passive external rotation if the insertion point was too high.

Conclusions: Transfer of the lower trapezius and rhomboid minor to the lesser tuberosity to reconstruct an irreparable subscapularis tear is feasible without extensive dissection and with a low risk of nerve compression. We recommend not to transfer the rhomboid minor routinely, owing to the risk of tendon luxation after external rotation of the shoulder.

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The prevalence of isolated subscapular tendon ruptures is between 3 and 10% among the total of rotator cuff tears.^{5,10,32} Most of these injuries are repairable. The exact prevalence of irreparable subscapularis tears is difficult to estimate, and nowadays, the surgical treatment continues to be a real challenge for surgeons.

Different surgical treatments have been proposed for this problematic injury.

Historically, numerous tendon transfers have been described pretending to reproduce and restore the force couples after a rotator cuff insufficiency, looking forward to obtaining pain relieve and improve function. Musculotendinous transfers were first implemented by hand surgeons routinely for the treatment of muscle palsies. From these experiences, it has been determined that several biomechanical principles are essential for a successful tendon transfer. The donor muscle unit needs to have a similar vector line in relation to the nonfunctioning muscle, and the

Institutional review board approval was not required for this cadaveric study.

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<https://doi.org/10.1016/j.jseint.2021.01.007>

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neurovascular pedicle must be free of tension. Similarly, the donor's tendon requires an analogous excursion, as well as relative tension and strength to perform its new function. Ideally, the transferred tendon should only replace 1 loss function.^{9,23}

One of the most used procedures for the treatment of irreparable subscapularis lesions has been the transfer of the pectoralis major, based on the principle that this muscle is an agonist of internal rotation of the shoulder.^{2,15,17,18,26,30,31,34,40,41,43,48} Originally described by Rockwood, this technique has faced different modifications over time.⁴⁸ Although these modifications should have biomechanical advantages from a theoretical standpoint, no technique has proven to be superior to another, taking into consideration the postoperative clinical results.^{15,18,31,34,40,43} Moreover, a pectoralis major tendon transfer has been proposed for isolated irreparable subscapularis injuries, as well as for anterosuperior rotator cuff insufficiency. Nonetheless, the pectoralis major transfer for anterosuperior lesions has shown less-favorable results. Another group at risk of failure with this procedure is patients with a preoperative anterior glenohumeral subluxation and instability.²⁶

Pectoralis minor tendon transfer has also been intended to substitute the function of the upper two-thirds of the subscapularis tendon or by irreparable anterosuperior massive rotator cuff tear.^{6,38,48,49} However, at the present, there is only low clinical evidence available with short-term follow-ups. The upper trapezius transfer has also been mentioned to improve pain and clinical scores but has failed to restore preoperative anterior subluxation of the humeral head.²¹

Although these techniques have been shown to improve pain in many patients, they have not been able to demonstrate a clear significant increase in strength, function and range of motion.^{15,26,34,40,45,48} These tendon transfers do not replicate the normal biomechanics of the subscapularis muscle. The line of pull of the subscapularis tendon has a posterior direction owing to its origin in the scapular fossa. In contrast, the pectoralis major originates from the anterior thorax compartment, having its origins in the medial clavicle half, the lateral manubrium, the sternum, and the six upper costal cartilages.⁷ In some shoulder positions, the vector line of the transposed pectoralis major is almost perpendicular in comparison with the subscapularis.^{14,27} Consequently, the humeral head is anteriorly translated rather than internally rotated, which could explain the poor outcomes with patients with preoperative anterior subluxation.^{8,15}

Owing to the aforementioned information, an alternative transfer has been proposed which attempts to replicate the subscapularis properties. The latissimus dorsi also produces internal rotation of the shoulder and has a synergistic function for the subscapularis.^{3,19,20,22,25,28,36} Furthermore, the tendon has a higher excursion than other candidates that intend to replace the functions of the subscapularis.²⁴ Moreover, the latissimus dorsi originates on the posterior side of the chest wall and in the axial plane have almost an identical line of pull of the subscapularis, producing biomechanical advantages in comparison with the pectoralis major and minor.^{14,27,35} The feasibility of this technique has been published, determining that the risk of compression of the neurovascular bundle is low after the transfer.¹⁴ Although the clinical outcomes can be compared with the scores to pectoralis major transfer, it seems like this technique could be superior in restoring the strength in internal rotation.^{27,35} Latissimus dorsi transfer could indeed be considered a good salvage procedure for irreparable subscapularis lesions. Nevertheless, the line of pull of this muscle in the coronal plane is almost 45° more vertical than the subscapularis.

Following the basic principles of tendon transfer and in line with the theory proposed by Elhassan et al,¹⁴ we believe that the lower trapezius has a similar biplanar direction of pull and force vector

than the subscapularis. This muscle also originates from the posterior region of thorax, specifically the spinous processes of the last thoracic vertebrae (T5-T12) to the dorsal surface of the scapula at the dorsal trapezius tubercle.³⁷ The different parts of the trapezius muscle work together to elevate, retract, and externally rotate the scapula. The lower trapezius helps to elevate the scapula during the arm elevation and plays a vital role in the stabilization of the scapula.²⁹

Theoretically, a lower trapezius transfer could prevent and better improve an anterior subluxation of the humeral head in comparison with other surgical techniques. For this reason, we proposed and studied the anatomic feasibility of the lower trapezius and the rhomboid minor transfer to reconstruct irreparable tendon tears of the subscapularis. The rhomboid minor is also another muscle of the posterior region, which has a traction vector similar to the subscapular. The primary function of the rhomboid muscle is fixing the scapula to the body and pulling it dorsomedially. Owing to its intimate anatomic relationship with the lower trapezius, we decided to include it in this study.

Materials and Methods

The study was performed preparing 10 fresh frozen cadavers (6 females and 4 males). There was no evidence of glenohumeral osteoarthritis or rotator cuff pathology on these cadavers. The specimens were positioned in the beach chair position, leaving 1 hemithorax free, to be able to dissect the back and front of the shoulders. At the back, an inverted L shaped incision was performed as well as a standard deltopectoral approach at the front, exposing all periscapular and shoulder muscles. The posterior deltoid was elevated for correct exposure of the trapezius. In the front of the shoulder, resection of the tendon of the subscapularis was performed, leaving only the muscle belly. Anatomic dissection was carefully executed, localizing and identifying the main neurovascular structures and the muscle bodies of the lower trapezius and rhomboid minor. All the dissections were performed by 1 of the authors.

The dissections and the measurement were performed in a similar fashion, following the protocol outlined by Elhassan et al.¹⁴ We proceeded to measure the dimensions of the tendons of the lower trapezius and rhomboid minor, precisely the width and length of the tendons (Fig. 1). The muscles excursions and the distances to the neurovascular pedicles were measured with a tape ruler in their maximal excursion (Fig. 2).

For the lower trapezius, we identified the distal insertion at the apex of the scapular spina, measuring the tendon length at the upper, middle and inferior portion. The width was determined at the myotendinous junction. Afterward, we detached the tendon of the lower trapezius from the footprint through a peeling technique, measuring the footprint area and the distance between the most lateral point of insertion of the tendon to the origin of his neurovascular pedicle (Fig. 2). We also recorded the maximal length from the tip of the tendon to the origin of the muscle at the spine of the scapula.

For the rhomboid minor, we performed the same measurements, with the exception that we recorded the tendon length only at its upper and inferior border. The rhomboid major was also evaluated to determine the length of its footprint at the medial border of the scapula as well as the distance from this point to the neurovascular pedicle.

Finally, we documented the distance needed to make the transfers; from the medial scapula border to the subscapularis footprint and from the scapular footprint to the subscapular footprint (center-to-center).

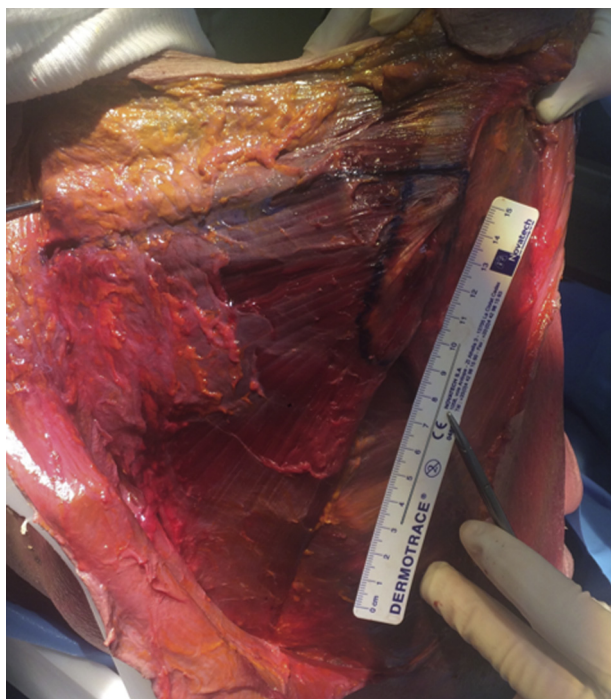


Fig. 1 Right shoulder view from the back. Measurement of the lower trapezius tendon.

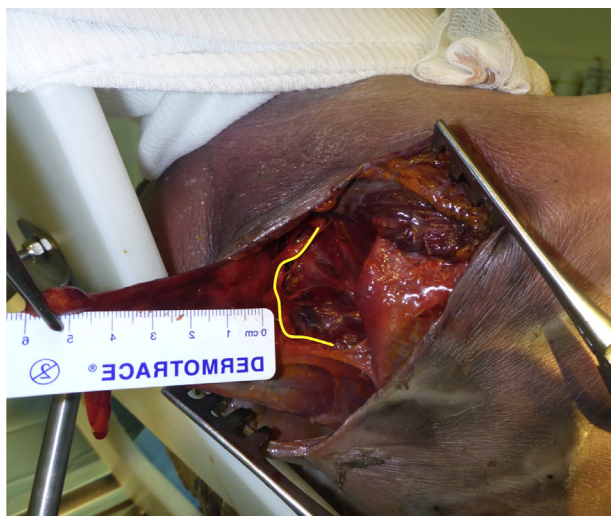


Fig. 2 Right shoulder view from the back. Lower trapezius pedicle distance measurement.

Lower trapezius and rhomboid minor transfer

The transferred muscles were prepared distally, augmented with a semitendinosus and gracilis autograft and passed anteriorly between the scapula and the subscapularis remnant through a small serratus window to reach the lesser tuberosity (Fig. 3). Less than a fascicle of the proximal border of the middle segment of the anterior serratus was detached. In the lesser tuberosity, the grafts were fixed with a knotless anchor (4.75-mm BioComposite SwiveLock anchor; Arthrex, Naples, FL, USA) in maximal external rotation and without forward flexion, placing the low trapezius transfer in the inferior third of the

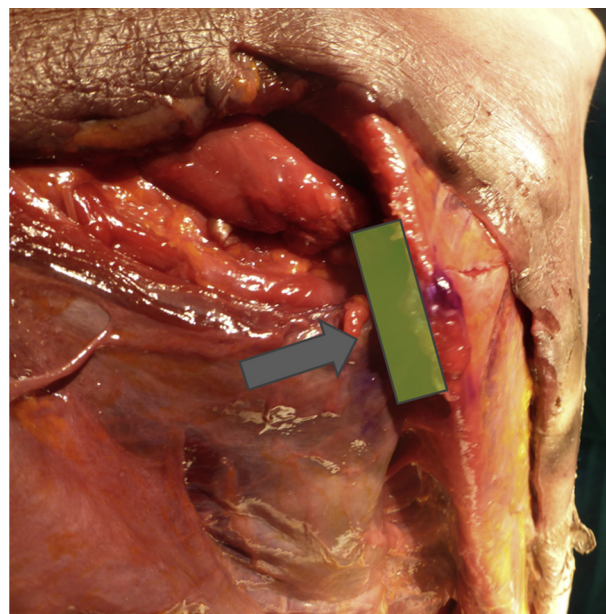


Fig. 3 Right shoulder view from the back. Serratus windows representing 2 digitations (green rectangle), direction of the transfer (blue arrow).

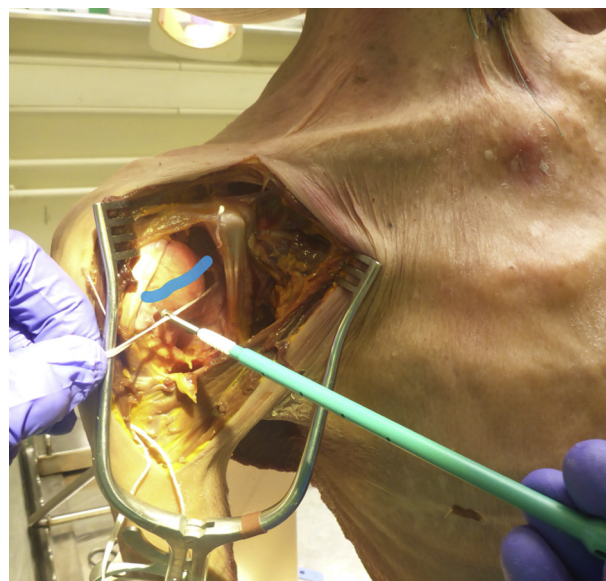


Fig. 4 Right shoulder view from the front. Lesser tuberosity fixation point for the lower trapezius (Sugaya zone 3).

subscapularis footprint and the rhomboid transfer resembling the upper subscapularis (Figs. 4 and 5).

We determined the dissection needed into the serratus to successfully transfer the lower trapezius and rhomboid minor transfer to the subscapularis footprint without developing any compression or impingement, measuring in three different arm positions; in neutral position (0° ER1), in adduction with maximal external rotation (90° ER1), and in abduction with maximal external rotation (90° ER2). The excursion of the tendon into the serratus anterior window was observed (Fig. 6). Furthermore, the necessity to partially detach some of the upper border of the rhomboid major to avoid changes of vector and conflicts with the trapezius was evaluated. The risk of pedicle compression was assessed in all cases



Fig. 5 Left shoulder view from the front. Tendon transfers fixation augmented with a semitendinosus and gracilis autograft in the footprint of the subscapularis tendon.

at the three different positions of the arm and was classified by 1 of the authors. It was subjectively categorized as no tension and minimum, mild, or severe compression.

Statistical analysis

The statistical analysis was carried out by a biostatistician. A priori power analysis was performed based on previous literature studies, estimating that the standard deviation between tendon dimensions and insertions is approximately ± 10 mm.¹⁴ We consider the effect size (0.2) and the standard deviation of ± 10 to have a clinical significance with 80% power, type of error II and with a significant level of 0.05. We calculated that 10 cadavers were necessary to perform the study. The outcomes will be presented with means and standard deviations between measurements. The measurements were recorded in millimeters and in percentage (in relation of the total length of the footprint). The SPSS program (version 23.0; IBM, Armonk, NY, USA) was used for all statistical analyses.

Results

Table I summarizes the most relevant results of this study. The mean age of the cadavers was 84.8 ± 5.5 years (range, 66–90 years), and the number of days after the death of the cadavers were 41.4 ± 70.5 days (range, 6–240 days).

The lower trapezius insertion tendon was asymmetric with a mean length size of $37.6 \text{ mm} \pm 9.4$ and mean width of $63.1 \text{ mm} \pm 9.9$. The neurovascular pedicle was in average $57.9 \text{ mm} \pm 13.6$

medial to the tip of the tendon. On the other hand, the rhomboid minor tendon had a mean length size of $21.7 \text{ mm} \pm 12.2$ and mean width of $33.4 \text{ mm} \pm 14.8$. The distance from the tendon to the neurovascular pedicle was in average $33.1 \text{ mm} \pm 4.6$.

The mean distances from the distal insertion of both tendons to the center of the lesser tuberosity were 109 ± 14.4 mm for the lower trapezius and 144 ± 13.9 mm for the rhomboid minor. Dissecting a serratus window is necessary to perform a tendon transfer from the posterior to the anterior region of the shoulder. The serratus windows of the superior portion of the middle segment had a mean size of $49.4 \text{ mm} \pm 15.2$, with a maximal excursion achieved at ER2 90°.

The upper border of the rhomboid major was released 17 mm on average. The tendon transfers procedures were feasible to perform in all the cadavers. Moreover, the risk of pedicle compression was found to have a minimal compression rate in 20% of the specimens for the trapezius (2 of 10) and 10% for the rhomboid transfer (1 specimen). No mild or severe compressions were detected in this study. In addition, a superior migration of the transfer was observed during passive external rotation when the insertion point was too high.

Discussion

The primary objectives of the treatment of irreparable subscapularis lesions are to restore the anterior force couple with anteroinferior stability of the humeral head and regain internal rotation. At the present time, no study has advocated the implementation of the lower trapezius for the treatment of anterior cuff insufficiency. The main finding of this study is the feasibility of the lower trapezius and the rhomboid minor tendon transfer with a tendon graft augmentation to the footprint of the subscapularis with a low risk of compression of the neurovascular pedicle of these tendons.

Topographically, the rhomboid minor is located just anterior and slightly superior of the lower trapezius. Both tendons could be reached with a relatively short single approach, and the process of harvesting the two tendons can be considered to be reasonably straightforward. To facilitate the transfer of the lower trapezius to the lesser tuberosity of the humerus, detachment of the insertion of the rhomboid minor in the scapula creating a small serratus anterior window seems to be the most practical solution. The dissection and detachment of two digitations of the serratus anterior (5 cm approximately) enable a good displacement of the transfer tendons to the subscapular fossa with a minimal compression risk of the neurovascular structures.

Another reason why we thought of using two complementary transfers was the need to completely cover the subscapularis footprint, which contains a large surface area.⁴ Moreover, the subscapularis muscle recently has been divided into two independent segments; a superior portion producing internal rotation of the humerus, and an inferior portion playing a fundamental role in the stabilization of the humeral head with posterior forces.^{39,47} This biomechanical feature could make an exception in the premise of 1 transfer for 1 lost function. In addition, the rhomboid minor and the lower trapezius are muscles of the posterior compartment of the thorax, which in the axial plane has the same line of pull that of the subscapularis muscle. However, in the coronal plane, the vector of the traction line of the rhomboid minor goes more superior in relation of the subscapularis.¹⁴ Hence, the new location of the rhomboid minor has less biomechanical advantages than the transposed trapezius. We also found that very proximal fixation of the tendon transfers leads to subluxation of the tendons after external rotation of the shoulder. For these reasons, we would recommend not to transfer the rhomboid minor, but instead

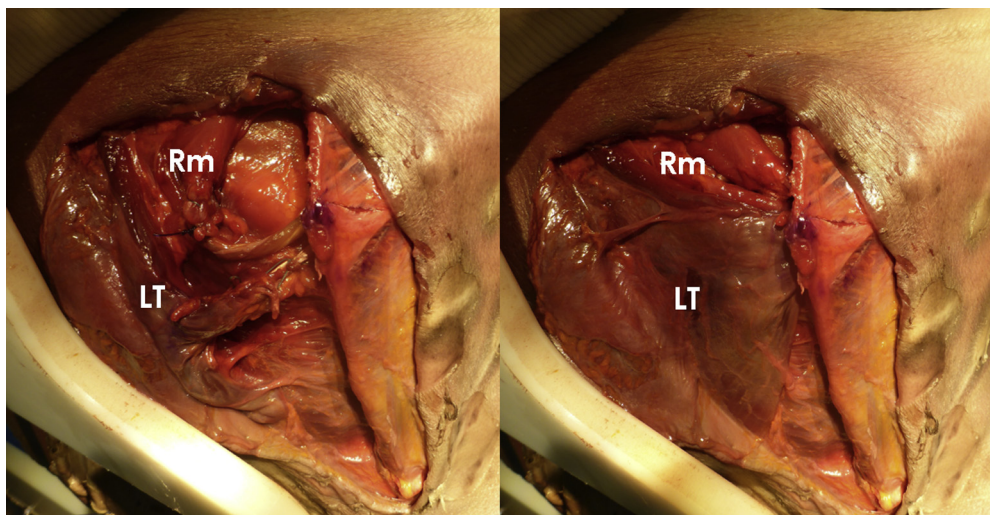


Fig. 6 Right shoulder view from the back. Tendon excursion in progressive external rotation. LT, lower trapezius; Rm, Rhomboid minor.

Table I
Cadaveric measurements of the tower trapezius and rhomboid minor.

Lower trapezius	Mean	SD	p50	Min	Max
Length of the tendinous portion					
Superior	29.4	7.8	30.5	14	42
Middle	37.6	9.4	37	27	55
Inferior	59.9	11.0	63.5	37	75
Width at the myotendinous junction	63.1	9.9	62	49	87
Insertion footprint size (%)					
Length	23.3	7.7	22	14	42
High	11.4	1.8	11	9	14
Distance from the lateral insertion to the NV pedicle	57.9	13.6	55	38	88
Rhomboid minus					
Length of the tendinous portion					
Superior	21.7	12.2	18	10	46
Inferior	16.8	9.9	16.5	3	35
Width at the myotendinous junction	33.4	14.8	35.5	12	56
Insertion Footprint size (%)	36.7	12.6	40	18	54
Distance from the lateral insertion to the NV pedicle	33.1	4.6	32.5	25	39
Rhomboid major					
Footprint RM	115.5	22.1	121	80	150
Desinsertion	17.4	6.7	18.5	0	24
Distance pedicle RM to lateral insertion	36	5.1	39	30	42
Measurements after transference					
Distance from the lower trapezius to the Lt	109	14.4	108	85	138
Distance from the rhomboid minor to the Lt	144.5	13.9	144	125	172
Diameter of the anterior serratus window					
0° ER1	37.1	12.4	42	20	55
90° ER1	48.6	17.1	49.5	25	69
90° ER2	49.4	15.2	50.5	29	69

Lt, lesser tuberosity; Rm, rhomboid minor; SD, standard deviation. All measurements are reported in millimeters.

reinsert it in its original location once the trapezius transfer has been performed. Another option is to use a wider achilles allograft to cover the entire subscapularis footprint rather than the thinner semitendinosus. We additionally advise the placement of the lower trapezius transfer in the midportion of the subscapularis footprint, specifically in Sugaya zone 3.⁴

The distance between the trapezius tendon entheses to the center of the subscapular footprint is approximately 10 cm. The trapezius muscle must be augmented with a tendon autograft or allograft to be able to reach the lesser tuberosity. This kind of lower trapezius transfer has demonstrated good clinical outcomes and no complications regarding tendon augmentation when used for posterolateral lesions, and no postoperative compression of the

neurovascular bundle of the lower trapezius has been reported.^{1,12,13,16,44} Although the tendon has another path when the transfer is made through the greater tuberosity to restore external rotation, we also found a low risk of compression when the tendon graft is directed anteriorly toward the lesser tuberosity. A minimally invasive technique can also be performed for fixation of the tendon graft with an arthroscopic-assisted approach. The graft fixation could be performed either by suture anchors, interference screw, or cortical buttons.

Moreover, the small serratus windows necessary to perform the lower trapezius transfer, will not add further morbidity and no significant loss in scapular protraction should be expected. This muscle has three portions. The serratus windows is performed

through a natural gap between the upper and middle segments, leaving intact the upper segment and detaching less than one-third of the middle portion. The inferior part is the biggest and most important segment, which also has a synergistic protraction effect.^{9,11,33,42,46}

The lower trapezius transfer may provide a similar line of pull in the axial and coronal planes compared with the subscapularis plane. This feature could replicate the shoulder kinematics, maintain anterior shoulder stability, and internal rotation strength. This novel procedure could be an alternative to previously published tendon transfers, especially in some specific situations; revision cases, when the pectoralis major or the latissimus dorsi tendon is not available (eg, nerve palsies) or maybe in multiple irreparable lesions in young patients. Further biomechanical and clinical studies are necessary to clarify the utility of this novel solution compared with other published transfers for irreparable subscapularis lesions.

This study has several limitations. First, we performed a cadaveric study, where the actual volume of the muscles can be underestimated. This may not represent the real relationship between the different anatomic structures, and impingement of the neurovascular pedicle could be misjudged. Second, the measurement of the neurovascular structure's compression risk was not measured with a calibrated pressure-sensitive device but rather performed using a subjective scale.

Conclusions

Transfer of the lower trapezius and rhomboid minor to the lesser tuberosity to reconstruct an irreparable subscapularis tear is feasible without extensive dissection and with a low risk of nerve compression. Nevertheless, we recommend not to transfer the rhomboid minor, owing to the risk of tendon luxation after external rotation of the shoulder. Further studies are necessary to clarify the biomechanical advantages of this novel procedure compared to other published transfers for irreparable subscapularis lesions. We think that the biplanar similarity in the pull line of the lower trapezius could work in harmony to replicate the functions of the subscapular muscle and could be another alternative to the already available transfers.

Disclaimers:

Funding: No funding was disclosed by the author(s).

Conflicts of interest: The authors, their immediate families, and any research foundations 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.

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