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

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- Lower trapezius
- Rhomboid minor
- Subscapular 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 laxation after external rotation of the shoulder.

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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.15,23

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.2,15,17,18,26,30,31,54,40,41,43,48 Originally described by Rockwood, this technique has faced different modifications over time.46 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 subscapular 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.21

Pectoralis minor tendon transfer has also been intended to substitute the function of the upper two-thirds of the subscapularis tendon on irreparable anterosuperior massive rotator cuff tears.15,30,40,49 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.9,10,27 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.14,21 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.14,21,25 The feasibility of this technique has been published, determining that the risk of compression of the neurovascular bundle is low after the transfer.15 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.22,25 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.14 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 subscapularis. 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 deltidoid 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 portions. The length 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).
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 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. 2 Right shoulder view from the back. Lower trapezius pedicle distance measurement.

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).
at the three different position 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. 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 1 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 decease 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 mm ± 9.4 and mean width of 63.1 mm ± 9.9. The neurovascular pedicle was in average 57.9 mm ± 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 mm ± 12.2 and mean width of 33.4 mm ± 14.8. The distance from the tendon to the neurovascular pedicle was in average 33.1 mm ± 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 mm ± 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 complimentary transfers was the need to completely cover the subscapularis footprint, which contains a large surface area. 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. 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. 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
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 enthesis to the center of the subscapularis 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 posterosuperior 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

### Table I

| 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 | | | | | |
| Length | 63.1 | 9.9 | 62 | 49 | 87 |
| Width at the myotendinous junction | | | | | |
| 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 | | | | | |
| Lower | 57.9 | 13.6 | 55 | 38 | 88 |
| Width at the myotendinous junction | | | | | |
| Length | 21.7 | 12.2 | 18 | 10 | 46 |
| Middle | 16.8 | 9.9 | 16.5 | 3 | 35 |
| Inferior | 18.4 | 14.8 | 18.5 | 12 | 56 |
| Width at the myotendinous junction | | | | | |
| Length | 33.4 | 14.8 | 35.5 | 12 | 56 |
| Width at the myotendinous junction | | | | | |
| Length | 33.7 | 12.6 | 40 | 18 | 54 |
| Distance from the lateral insertion to the NV pedicle | | | | | |
| Lower trapezius | 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 |
| Rhomboid minor | | | | | |
| Insertion Footprint size (%) | 36.7 | 12.6 | 40 | 18 | 54 |
| 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 |
| Measurements after transference | | | | | |
| 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.
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.  

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 (e.g., 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 muscles cannot be 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 laxation 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 subscapularis muscle and could be another alternative to the already available transfers.

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References

1. Albinde WR, Elhassan BT. Lower trapezius augmentation with Achilles tendon augmentation: indication and clinical results. Obere Extrem 2013;18:1297-2. https://doi.org/10.1016/j.oe.2013.12.002.
2. Aldridge JM, Atkinson TS, Mallon WJ. Combined pectoralis major and latissimus dorsi tendon transfer for massive rotator cuff deficiency. J Shoulder Elbow Surg 2004;13:621-9. https://doi.org/10.1016/j.jse.2004.03.003.
3. Aoki M, Okamura K, Fukushima S, Takahashi T, Oigo T. Transfer of latissimus dorsi for irrepairable rotator cuff tear. J Bone Joint Surg Br 1996;78:761-6.
4. Arari R, Sugaya H, Mochizuki T, Ninomiya K, Morishita J, Akita K. Subscapularis tendon: an anatomic and clinical investigation. Arthroscopy 2008;24:997-1004. https://doi.org/10.1016/j.arthro.2008.04.076.
5. Boaright JD, Crow AJBSF. Pectoralis Major Tendon Transfer. In: Guolotta LV, Craig EV, editors. Massive Rotator Cuff Tears. Boston, MA: Springer; 2015. Available at: http://link.springer.com/10.1007/978-1-4899-7494-5#doi:10.1007/978-1-4899-7984-5.
6. Cartaya M, Werthel J-D, Valenti P. Arthroscopic-assisted pectoralis minor transfer for irreparable tears of the upper two-thirds of the subscapularis tendon: technical technique. Arthrosc Tech 2017;6:e1501-5. https://doi.org/10.1016/j.arthro.2017.05.010.
33. Martin RM, Fish DE. Scapular winging: anatomical review, diagnosis, and treatments. Curr Rev Musculoskelet Med 2008;1:1-11. https://doi.org/10.1007/s12178-007-9000-5.
34. Moroder P, Schulz E, Mitterer M, Plachel F, Resch H, Lederer S. Long-term outcome after pectorals major transfer for irreparable anterosuperior rotator cuff tears. J Bone Joint Surg Am 2017;99:239-45. https://doi.org/10.2106/JBJS.16.00485.
35. Mun SW, Kim JY, Yi SH, Baek CH. Latissimus dorsi transfer for irreparable subscapularis tendon tears. J Shoulder Elbow Surg 2018;27:1057-64. https://doi.org/10.1016/j.jse.2017.11.022.
36. Oh JH, Ilhan J, Chen Y-J, Chung KC, McCary MH, Lee TQ. Biomechanical effect of latissimus dorsi tendon transfer for irreparable massive cuff tear. J Shoulder Elbow Surg 2013;22:150-7. https://doi.org/10.1016/j.jse.2012.01.022.
37. Paladini P, Campi F, Merolla G, Pellegrini A, Porcellini A. Pectoralis minor tendon transfer for irreparable anterosuperior cuff tears. J Shoulder Elbow Surg 2013;22:e1-5. https://doi.org/10.1016/j.jse.2012.12.030.
38. Rathi S, Taylor NF, Green RA. The upper and lower segments of subscapularis muscle have different roles in glenohumeral joint functioning. J Biomech 2017;63:92-7. https://doi.org/10.1016/j.jbiomech.2017.08.007.
39. Shin J, Saccomanno MF, Cole BJ, Romeo AA, Nicholson GP, Verma NN. Pectoralis major transfer for treatment of irreparable subscapularis tear: a systematic review. Knee Surg Sports Traumatol Arthosc 2016;24:1951-60. https://doi.org/10.1007/s00167-014-3229-5.
40. Smith R, Nyquist-Batte C, Clark M, Rains J. Anatomical characteristics of the upper serratus anterior: cadaver dissection. J Orthop Sport Phys Ther 2003;33:449-54. https://doi.org/10.2519/jospt.2003.33.8.449.
41. Valenti P, Boughhebi O, Moraiti C, Dib C, Maqdes A, Amouyel T, et al. Transfer of the clavicular or sternocostal portion of the pectoralis major muscle for irreparable tears of the subscapularis. Technique and clinical results. Int Orthop 2015;39:477-83. https://doi.org/10.1007/s00264-014-2566-9.
42. Wirth MA, Rockwood CA. Operative treatment of irreparable anterosuperior massive rotor cuff tear. Arthrosoc Tech 2018;7:e193-8. https://doi.org/10.1016/j.eats.2017.08.070.