Research Article

Tendon Transfer Options for Trapezius Paralysis: A Biomechanical Study

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Abstract

Introduction: The purpose of this study was to evaluate the biomechanical effectiveness regarding scapulothoracic (ST) upward rotation of two different tendon transfer procedures involving the levator scapulae, rhomboid major, and rhomboid minor to restore the function of the paralyzed trapezius.

Methods: Six fresh frozen hemithoraces were mounted on a custom-built apparatus. A three-dimensional electromagnetic tracking system was used to record ST upward/downward rotation of the (1) normal trapezius, levator scapulae, rhomboid minor, and rhomboid major; (2) Eden-Lange (EL) transferl and (3) a modified EL transfer (triple transfer).

Results: The normal trapezius was found to be an upward rotator of the scapula and led to a mean ST rotation angle of 26.98°. Similarly, the modified triple transfer led to an upward rotation of the scapula, with a mean ST rotation angle of 22.23°, whereas the EL led to an initial downward rotation of the scapula to −6.69°, with a mean scapulothoracic displacement angle of 1.13°.

Discussion: The upward rotation of the scapula from the modified transfer mimicked the function of the normal trapezius better than did the traditional EL transfer.

Level of Evidence: Level V, biomechanical study

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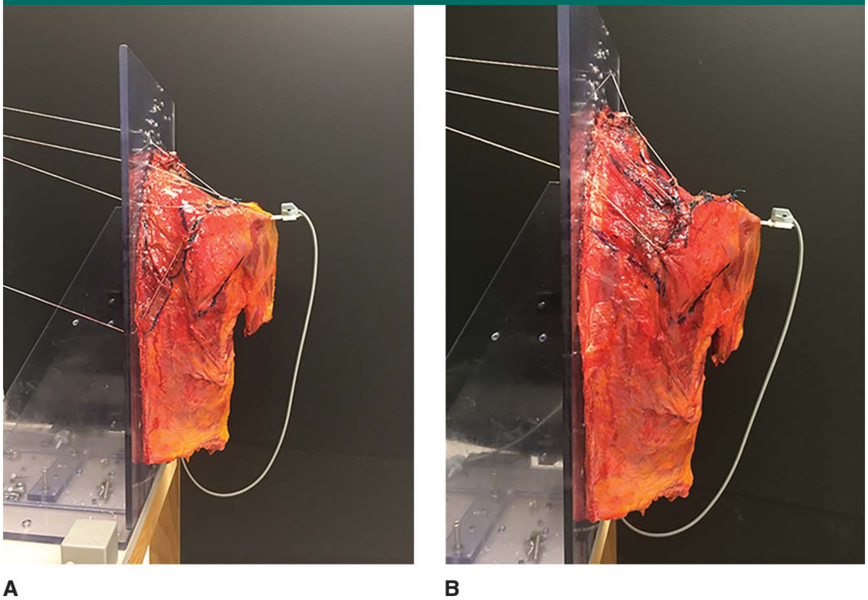
Normal shoulder motion depends on the combined function of the glenohumeral (GH) joint and scapulothoracic (ST) articulation. It was estimated that the motion is approximately divided into 2/3 originating from the GH joint and 1/3 from the ST articulation.[1,2] The ST motion depends mainly on the serratus anterior (AT) muscle that stabilizes the scapula on the chest wall and the trapezius muscle that suspends the scapula on the chest wall and plays a major role in the ST motion, specifically during shoulder abduction. This is achieved by scapular upward rotation that in turns allows a more complete abduction by maintaining the acromiohumeral distance and the deltoid resting length.[2] Loss of trapezius function leads to drooping of the shoulder, loss of scapula external rotation with secondary loss of abduction (and later flexion), and possible subacromial bursitis because of scapula internal rotation and winging.[2,3]

Limited described surgical options exist for patients with chronic symptomatic trapezius paralysis. The most commonly reported procedure described for the management of this condition is the Eden-Lange (EL) procedure that entails transfer of the levator scapulae (LS) to the lateral spine of the scapula and rhomboid

Figure 1



A and **B**, Photographs showing a hemitorso mounted on a custom-made apparatus. The contour lines of the scapula and of the trapezius muscles are represented. **A**, Four cords simulate the lines of pull of the anterior, upper, middle, and lower trapezius. **B**, The trapezius muscle has been removed, and three cords simulate the lines of pull of the levator scapulae, rhomboid major, and rhomboid minor.

major (RM) and minor (Rm) to the infraspinatus fossa to reconstruct the function of the lost trapezius.[4-8]

However, the reported outcomes of this procedure, including its modified version (in which the RM is transferred to the infraspinatus fossa and the Rm to the supraspinatus fossa), showed variable results with inconsistently positive outcomes.[3,9-14] This variability in the outcome could be related to abnormal ST motion and shoulder biomechanics created by the described tendon transfers. Recently, a triple muscle transfer (ie, a modification of the EL in which the LS was transferred to the spine of the scapula just medial to the acromion; the Rm was transferred to the spine of the scapula just medial to the LS insertion, and the RM was transferred to the spine of the scapula just medial to the Rm insertion.) has been described with excellent outcomes.[15]

To our knowledge, biomechanical evaluation of transfer of the RM, Rm, and LS to different locations on the posterior aspect of the scapula to reconstruct a paralyzed trapezius has not been previously performed. The purpose of this study was to evaluate and compare the biomechanical effectiveness regarding ST upward rotation of LS, RM, and Rm transfers when performed to different locations around the posterior scapula to try to restore the upward rotation of the paralyzed trapezius.

Methods

Preparation of the Cadaver Specimens and Creation of the Shoulder Model

The study used six fresh frozen cadaver specimens (four men and two women; mean age, 86 years [±7.71]), which were thawed a few hours before testing. We used a novel shoulder model that we published about previously.[16] In this model, we used the right hemithoraces and shoulder girdles for each specimen. Fluoroscopy was used before dissection, and specimens were excluded if any GH joint pathology was found. After dissection, the shoulder joint, capsule, and muscles were carefully examined, and specimens were excluded if any gross abnormality, including arthritis or rotator cuff tear, was found.

The cadaver specimens were prepared as follows. The upper (UT) extremities were cut at the proximal humerus. The cadaver heads were removed, while sparing the cervical vertebrae to preserve most of the proximal origin of the trapezius and LS muscles. The pelvis was also removed, and the thorax and abdomen were eviscerated. The spine, sternum, rib cage, and all other muscles of the thorax, back, and shoulder girdle were preserved.

The skin and subcutaneous tissues were carefully dissected away, and the origins and insertions of the trapezius, LS, RM, and Rm were identified. Each specimen was mounted on a custom-built apparatus (Figure 1). The spinal column was fixed to the testing apparatus with screws, and the anatomic lordotic and kyphotic curvatures were maintained.

Assessment of the Scapulothoracic Rotation

A three-dimensional electromagnetic tracking system, Polhemus Fastrak, was used to record raw kinematic data. The Fastrak system tracks the position and orientation (ie, 6° of freedom) of several sensors as they move through space in relation to a transmitter. Sensors were attached to the thorax and scapula, and coordinate systems were established according to the International Society of Biomechanics recommendations for the bones.[17] ST joint angles were calculated using Euler angles to measure the upward and downward rotation of the lateral part of the scapula in the coronal plane. By convention, upward rotation was formulated as a positive angle, and downward rotation as a negative angle.

Modeling of the Muscles and of the Tendon Transfers

Cords attached to the anatomic origins and insertions of muscles were used to model their lines of action. Briefly, transosseous sutures were placed in the insertions, whereas the origins were marked and fitted to accept the passage of the cord through an eye screw. The trapezius muscle was divided into four parts (ie, AT, UT, middle [MT], and lower [LT]), each replicated by one cord (Figure 1). It is worth noting that the UT trapezius was divided into two parts because the line of pull of the AT (ie, clavicular) portion is different from that of the rest of the UT.

After testing of the trapezius, it was carefully excised to expose the underlying muscles. The LS, RM, and Rm were each modeled by one cord (Figure 1).

To replicate the lines of action of the tendon transfers, the anatomic origins of the muscles were maintained, whereas their insertion sites were modified to replicate the different transfers. Each cord was passed from the insertion site (ie, anatomic or transferred), through the origin of the muscle, and finally attached separately to pneumatic pistons.

Motion

For each trial, the motion was performed by increasing the pressure to all the pneumatic actuators simultaneously at a steady rhythm of 1 N every 5 seconds, until the full scapular motion (upward rotation) had been achieved. We defined the terminal extent of scapular motion to be the point when additional pressure in the actuators did not lead to any motion. Each condition was tested three times. The force was equally applied in each muscle segment. The difference between the final and the initial rotations of the scapula was recorded to obtain the ST rotation of each trial. The mean ST rotation of the three trials was recorded. The goal was to simplify the experimental setup to focus only on the effect of the line of pull of different muscles on upward rotation of the scapula on the chest wall. Therefore, we intentionally did not load other ST or scapulohumeral muscles (eg, pectoralis minor, latissimus dorsi, serratus AT). Although these ST muscles are important stabilizers of the scapula, their role in scapular upward rotation is minimal. In addition, we intentionally did not apply physiologic loads because based on our past experience, the application of physiologic forces led to complete tears of the muscles (because no internal tension exists in the cadaver muscles).

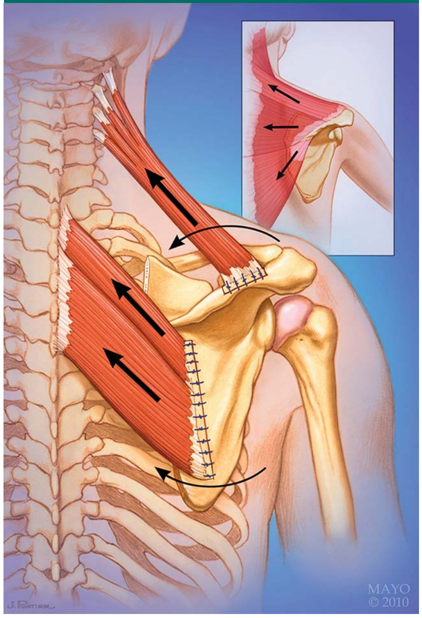
Eden-Lange Procedure

The EL transfer[1,4,18] was reproduced as follows: the LS was inserted to the superior surface of the lateral part of the scapular spine before it becomes the acromion.[4-7] The RM and Rm were transferred laterally together to the posterior body of the scapula in the infraspinatus fossa (Figure 2).

Modification of the Eden-Lange Transfer

To reproduce more accurately the line of action of the trapezius muscle, a modification of the EL transfer was included[15] (Figure 3). In this modification, the LS was transferred to the spine of the scapula just medial to the acromion. The Rm was transferred to the spine of the scapula just medial to the LS insertion, and the RM was transferred to spine of the scapula just medial to the Rm insertion.

Figure 2



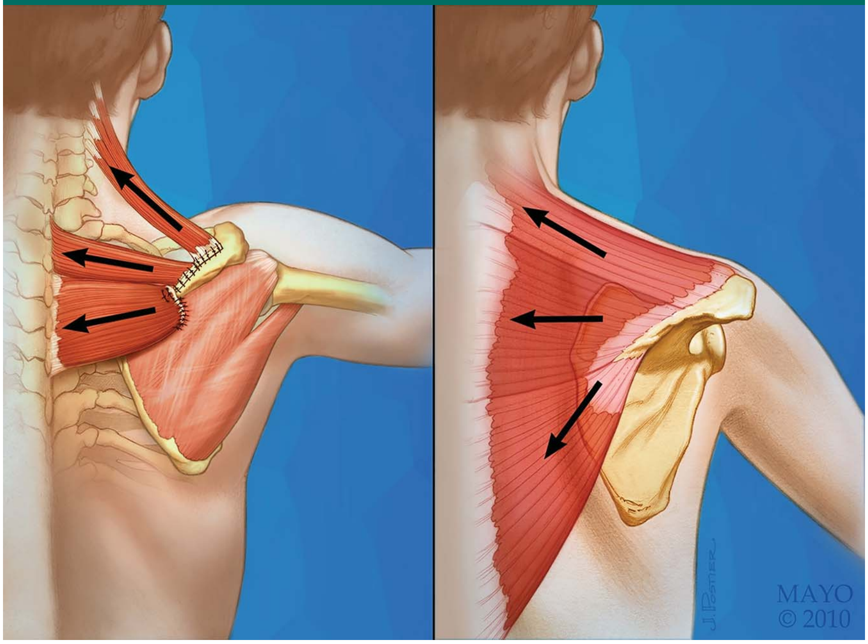
Diagrams showing lines of action of the Eden-Lange transfer (left) compared to the lines of action of the different subregions of the trapezius (upper right). (Reproduced with permission from the Mayo Education Foundation for Medical Education and Research, Rochester, MN.)

Results

Intact Muscles

When the normal trapezius function was replicated, it was found to be an upward rotator of the scapula and led to a mean ST upward rotation of 27° (range, 23° to 32°) (Figures 4 and 5). The mean initial resting position of the scapula was 5.87°. The mean final resting position of the scapula was 32.85°. When loading the different parts of the trapezius individually, the UT was found to be the main upward rotator (ie, external rotator) of the scapula (31°; range, 30° to 34°), whereas the MT and LT were found to also externally rotate the scapula, but to a lesser extent than the UT, with a mean ST upward rotation of 21° (range, 20° to 22°) and 12° (range, 11° to 14°), respectively.

Figure 3



Diagrams showing lines of action of the modified Eden-Lange transfer (left) compared to the lines of action of the different subregions of the trapezius (right). The levator scapulae (LS) is transferred medial to the acromion, the rhomboid minor (Rm) to the spine of the scapula just medial to the LS, and the rhomboid major medial to the Rm. (Reproduced with permission from the Mayo Education Foundation for Medical Education and Research, Rochester, MN.)

The LS was found to rotate the scapula downward to −6° (range, −4° to −8°). The loading of the rhomboids led initially to a downward rotation of the scapula of −4° (range, −3° to −5°), which, as the scapula was translated medially and superiorly, was followed by an upward rotation of 14° (range, 12° to 15°).

Eden-Lange Transfer

The activation of the transferred muscles in the EL setting led to a downward rotation of the scapula of a mean −7° (range, −3° to −14°) at the beginning of the motion (Figures 4 and 5). In all six specimens, the initial medial and proximal translation of the scapula over the thorax altered of the center of rotation of the scapula relative to the tendon transfer insertions, eventually leading them to become upward rotators. The mean final upward rotation of the scapula was 1° (range, −7° to 10°). The mean initial resting position of the scapula was 4.87°. The mean final resting position of the scapula was 6.02°.

Modified Eden-Lange Transfer

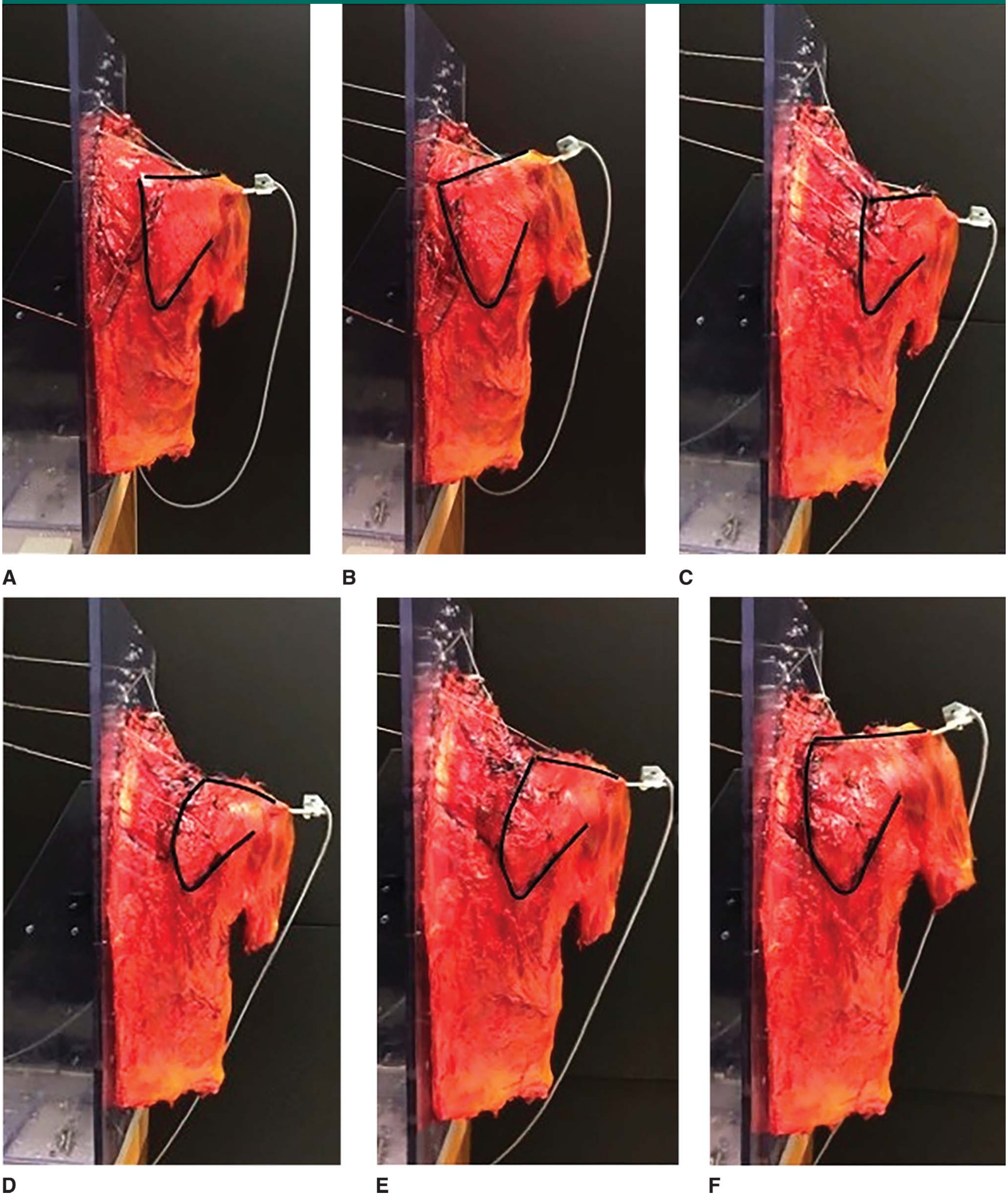
The activation of the transferred muscles in the modified EL setting led to an upward rotation of the scapula, with a mean upward rotation angle of 22° (range, 13° to 29°) (Figures 4 and 5). The mean initial resting position of the scapula was 0.57°. The mean final resting position of the scapula was 22.91°.

Discussion

By upwardly rotating the scapula during overhead activities, the trapezius enables optimal function of the shoulder joint. It positions the glenoid for optimal alignment with the moving humeral head to allow maximum efficiency of the deltoid and rotator cuff muscles,[2,9,19,20] and it lifts the acromion away from the rotator cuff to prevent coracoacromial impingement.[19] Lockhart[21] in 1930 reported that it is impossible to abduct the humerus beyond the horizontal with the scapula fixed on the chest wall. Furthermore, he observed in a 19-year-old patient with trapezius paralysis that the deltoid could only move the humerus until it was at right angle to the scapula. This shows the importance of the ST motion in achieving overhead activities.[1,2] The relationship between abduction of the GH angle and upward rotation of the scapula enables optimal positioning of the joint throughout abduction. Although the ST motion is not perfectly homogeneous among different subjects for the first 30° of humerothoracic abduction, once this position is reached, the scapula and humerus follow a coordinate pattern with a scapulohumeral rhythm of 2.3.[1]

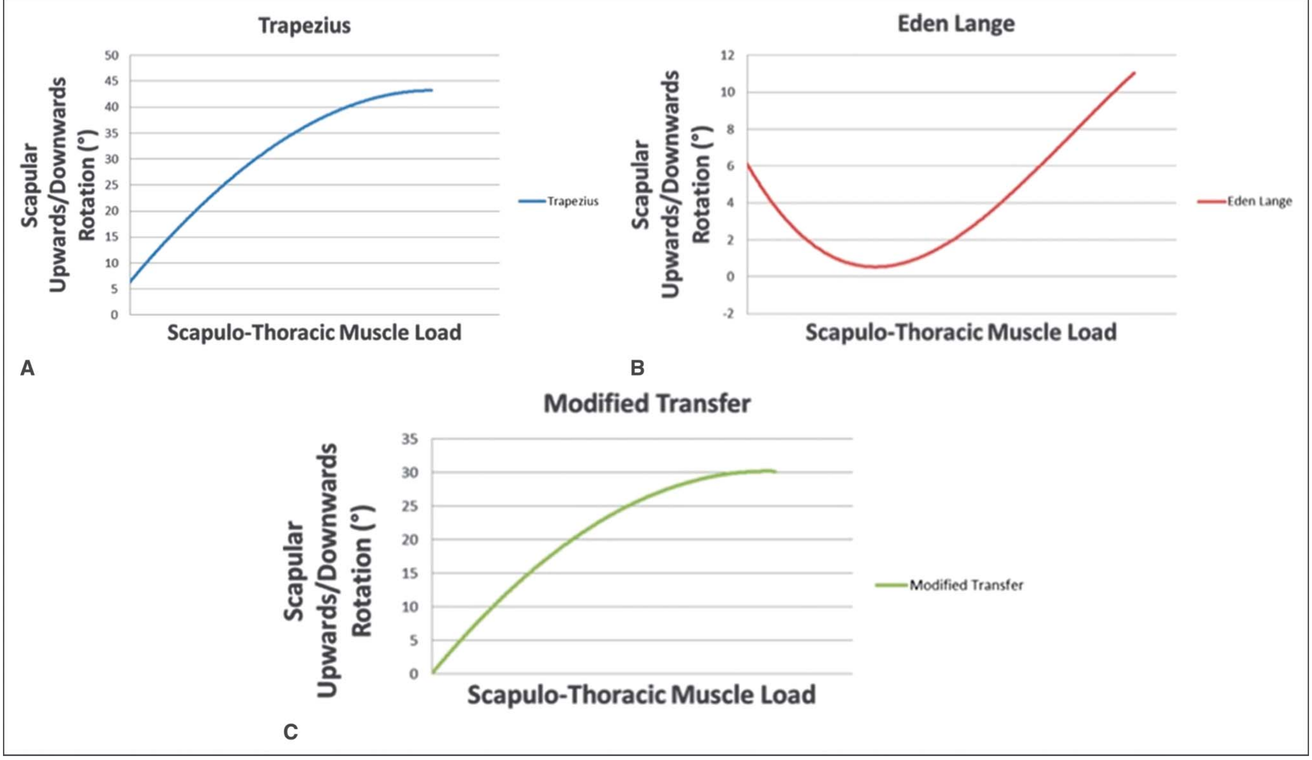
The main muscle involved in the upward rotation of the scapula is the trapezius as our study has confirmed. This was true for every subdivision of the trapezius muscle (ie, AT, UT, MT, and LT). In the setting of loss of trapezius function, mostly secondary to paralysis from nerve injury, and uncommonly secondary to injury or detachment of the trapezius muscle, the absence of upward rotation of the scapula leads to painful limitation of abduction. Nerve surgery can be performed with variable results.[18,22-27] When nerve repair or muscle repair is not possible or unsuccessful, tendon transfer remains the main treatment option for the absent trapezius function.[3,9,14,18] The most commonly described transfer include isolated transfer of the LS[18] or combined LS

Figure 4



Photographs showing the starting (**A**) and ending (**B**) positions of the scapula when loading the trapezius alone. Photographs showing the starting (**C**) and ending (**D**) positions of the scapula when loading the levator scapulae (LS) and rhomboids in the setting of an Eden-Lange transfer. Photographs showing the starting (**E**) and ending (**F**) positions of the scapula when loading the LS and rhomboids in the setting of a modified Eden-Lange transfer (triple transfer). The scapula rotates in an upward direction in conditions **B** and **F** as opposed to condition **D** where the scapula is seen to rotate downwardly.

Figure 5



Graphs showing average scapulothoracic angles when progressively loading the trapezius (**A**), the levator scapulae and rhomboids in the setting of an Eden-Lange transfer (**B**), and in the setting of a modified Eden-Lange transfer (**C**). As opposed to what is seen in conditions **A** and **C**, the scapula starts by rotating downward in condition B.

transfer with the rhomboid muscles (ie, EL procedure).[4-8] These have been shown to provide various results throughout the literature. Bigliani et al[9,18] and Romero and Gerber[12] described the restoration of a painless functional shoulder after EL transfer, whereas Teboul et al[3] reported poor results after this procedure.

The results in this study showed that the LS and the rhomboidei were downward rotators of the scapula. When the LS is transferred to the lateral spine of the scapula, it changes into an upward rotator of the scapula. However, the insertions of the RM and Rm are then lateralized by performing the transfer to the body of the scapula. This in turn magnifies the downward rotation moment arm of the transferred muscles. The results in our study showed that the downward rotation of the scapula that was caused by the EL transfer was combined with medial and proximal translation of the scapula over the thorax leading to a modification of the center of rotation of the scapula relative to the muscular insertions. This change of the center of rotation explains the upward rotation observed later in the motion. When these findings are translated into the clinical setup, it would be expected that as the patient initiates an overhead movement of the shoulder, the EL transfer is activated, and the scapula is pulled into downward rotation. This contradictory downward rotation of the scapula places the supraspinatus and MT deltoid at a disadvantage for optimal function. The variability in outcome reported after the EL procedure observed in the literature[3,9-14,18] could be related to the abnormal biomechanics created by the EL transfer.

In contrast, the modified transfer did replicate the mechanics of normal trapezius, and its activation led to upward rotation of the scapula in a reproducible fashion. These results are consistent with a recently reported clinical retrospective study of 22 cases,[15] which showed that the modified technique provided notable improvement in pain and range of motion at an average 35-month follow-up. However, there are no clinical comparison studies to date between the traditional EL transfer and the modified transfer.

Our study has three main limitations. First, we analyzed only one motion of the scapula (ie, upward-downward rotation) without considering variations in translation, anteroposterior and mediolateral rotation, or glenohumeral motion. However, the trapezius is almost an exclusive upward rotator of the scapula, so this is the main movement a palliative transfer should reproduce. Second, the loads we applied were equally distributed among the different muscles or muscle subregion, regardless of the muscle size and force-generating capacity of the different muscles. This, however, enabled us to have a standardized reproducible method for each trial. Finally, important scapular muscles such as the serratus AT were not loaded. The function of the serratus is important in stabilizing the scapula on the chest wall. In the current model, we chose to focus on the upward rotation of the scapula. In this movement, the function of the serratus becomes less important. In addition, this potential variable should not affect the results because the same exact experimental setup and values were applied equally on all trials.

Conclusion

In conclusion, the findings of this study showed that the modified transfer of the LS, Rm, and RM did lead to an ST upward rotation that replicated that of the normal trapezius. In contrast, the EL transfer showed a contradictory abnormal ST rotation compared with a normal trapezius rotation. These findings indicate that in the clinical setting, the modified transfer when performed to treat trapezius paralysis may potentially lead to better functional outcome because it better replicates the normal trapezius function.

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