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Biomechanical effectiveness of tendon transfers to restore active internal rotation in shoulder with deficient subscapularis with and without reverse shoulder arthroplasty

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Background: Loss of active shoulder internal rotation can be very disabling. Several tendon transfers have been described for the management of an irreparable subscapularis (SSC) tear. The purpose of this study was to determine and compare the internal rotation moment arm (IRMA) of the sternal head of the pectoralis major (PM), latissimus dorsi (LD), and teres major (TM) when transferred to different insertion sites to restore shoulder internal rotation with and without reverse shoulder arthroplasty (RSA).

Methods: Six fresh-frozen right hemithoraces were prepared and evaluated using a custom tendon transfer model to determine the IRMA of different tendon transfers using the tendon and joint displacement method. Five tendon-transfer pairs were modeled using a single suture and tested before and after implantation of an RSA (Comprehensive; Zimmer-Biomet, Warsaw, IN, USA): PM to the insertion site of the SSC, LD to the anterior insertion site of the supraspinatus (SSP) tendon on the greater tuberosity, LD to SSC, TM to SSP, and TM to SSC. The SSC was not repaired at the end of the RSA procedure to simulate an SSC deficiency. The PM transfer was passed under the conjoined tendon when tested on the intact shoulder and above the conjoined tendon when tested with an RSA.

Results: Tendon transfers were shown to have a significant effect on IRMA. The effect of transferred tendons was significantly affected by the position of the humerus. With the humerus adducted, the IRMA of the TM-SSP (14.1 mm ± 3.1 mm) was significantly greater than the other transfers. With the humerus abducted to 90°, the IRMAs of the LD-SSP (30.0 mm ± 5.4 mm) and TM-SSP (28.4 mm ± 6.6 mm) were significantly greater than the IRMAs of other transfer options. The IRMA of the native shoulder differed significantly from that of the RSA state for all tendon transfers. With the humerus adducted to the side of the body, the IRMA of the RSA PM-SSC transfer was significantly greater than that without an RSA (19.0 mm ± 6.4 mm vs. 7.1 mm ± 0.9 mm), demonstrating increased efficiency for internal rotation in the RSA state.

Conclusion: Tendon transfers to restore shoulder internal rotation differ in effectiveness and may be affected by arm position and by implantation of a lateralized humerus/lateralized glenoid RSA. The LD potentially results in superior restoration of shoulder internal rotation in a native shoulder (given the risk of nerve compression with the TM transfer) compared with PM and should be considered as a potential tendon transfer to restore internal rotation in selected patients. In combination with a lateralized humerus/lateralized

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glenoid RSA, the fulcrum provided by the biomechanics of the semiconstrained implant allows the PM transfer to become a more efficient tendon transfer to restore active internal rotation.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Reverse shoulder arthroplasty; tendon transfer; irreparable rotator cuff tear; subscapularis tear; internal rotation; latissimus dorsi; pectoralis; teres major

Loss of active shoulder internal rotation can be very disabling. The most common cause of loss of internal rotation is irreparable tearing of the subscapularis (SSC) tendon. Patients usually experience pain and may exhibit anterior apprehension, subluxation/instability, and pseudoparalysis.[6,13]

Loss of active shoulder internal rotation can also be seen in patients who undergo reverse shoulder arthroplasty (RSA). In this setting, although patients experience significant improvement in shoulder motion, gains in shoulder internal rotation can be very unpredictable.[1,15,23] It has been shown that the repair of the SSC may improve postoperative internal rotation, especially if the repair is proven to be healed;[5] however, outcomes are not consistent.[10,11,16]

Several tendon transfers have been described for the management of an irreparable SSC tear. The most common transfer reported is the pectoralis minor[4,20] or the pectoralis major (PM).[26] Several studies have shown satisfactory long-term results after the transfer of the sternal head of the PM tendon.[9,17,19,22] However, other reports have shown poor outcomes of this transfer, especially in patients with concurrent anterior instability.[8,19] Poor outcomes with the PM transfer may be due to the fact that the line of pull of the PM does not replicate that of the SSC. An ideal tendon transfer should adhere to 5 basic biomechanical principles: the transferred muscle must have a similar (1) line of pull, (2) tension, and (3) excursion to that of the muscle replaced; (4) 1 transfer should be used to replace only 1 deficient function; and (5) the donor muscle must have normal strength. When evaluating the location and line of pull of the PM compared with the SSC, the sternal head of the PM originates from the anterior chest wall, whereas the SSC originates from the anterior scapular body, which is positioned on the posterior aspect of the chest wall (Fig. 1). In 2014, Elhassan et al[7] described the feasibility of transferring muscle posterior to the chest wall (teres major [TM] or latissimus dorsi [LD]) anteriorly to replicate the line of pull of the SSC muscle. To our knowledge, no study has evaluated the outcome of tendon transfers to restore internal rotation after RSA. Also, although an anatomic study has been performed to prove the feasibility of the transfer of the latissimus and/or TM to reconstruct an irreparable SSC, no prior biomechanical study has evaluated the effectiveness of these transfers or the pectoralis transfer to

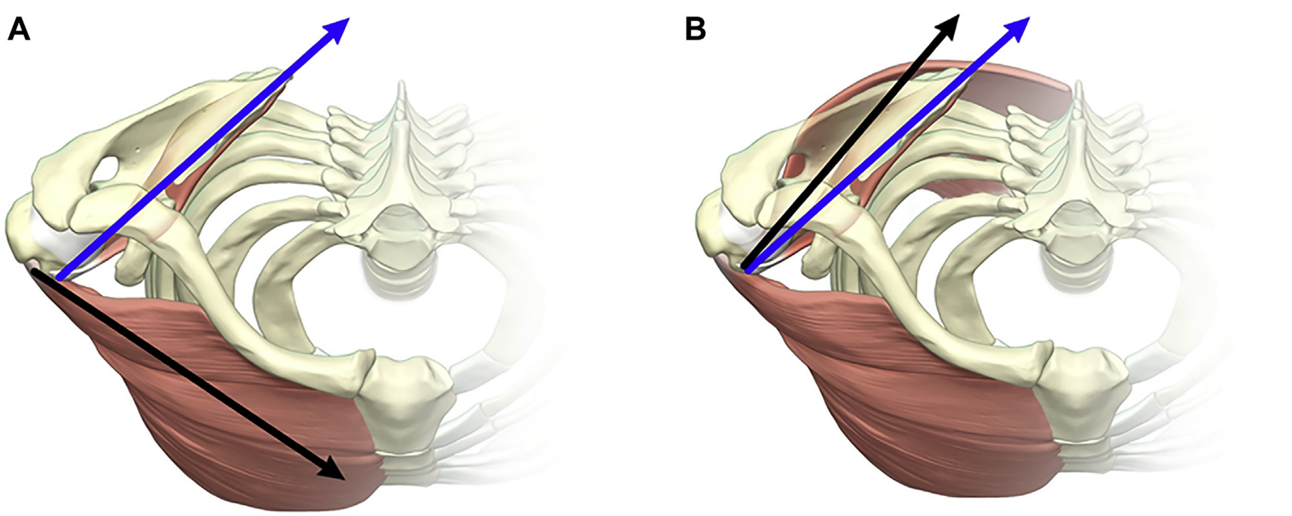

Figure 1 Illustration of the vectors of the different internal rotation tendon transfers available. (**A**) The line of pull of the pectoralis major (black arrow) compared with the subscapularis (blue arrow): the sternal head of the pectoralis major originates from the anterior chest wall, whereas the subscapularis originates from the anterior scapular body, which is positioned on the posterior aspect of the chest wall. (**B**) The line of pull of the teres major/latissimus dorsi (black arrow) compared with the subscapularis (blue arrow): the teres major and the latissimus dorsi originate from the posterior aspect of the chest wall similarly to the subscapularis.

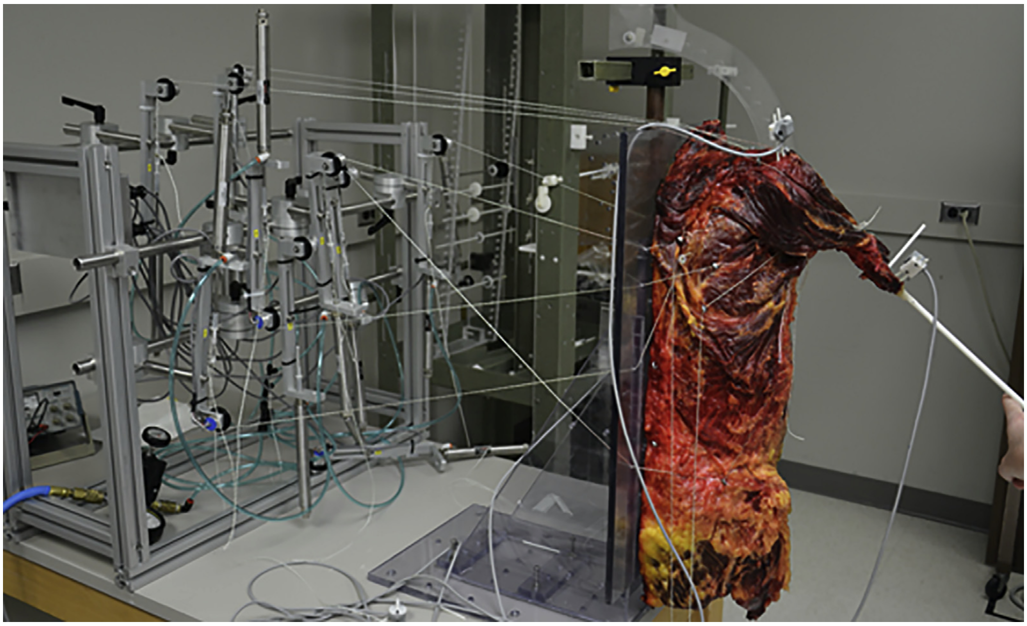

Figure 2 The custom-made experimental setup shown with cadaver hemisection allows modeling of axiohumeral tendon transfers.

restore shoulder internal rotation to the native shoulder with a deficient anterior rotator cuff tear or in a shoulder with RSA. The purpose of this study was to determine and compare the internal rotation moment arm (IRMA) of different types of tendon transfers to restore shoulder internal rotation with and without RSA.

Methods

Cadaveric shoulder model

Six fresh-frozen right hemithorax/shoulder girdle cadaveric specimens (4 men, 2 women) were used for this study. The mean age of the specimens at the time of death was 86 years (±7.71). Fluoroscopic imaging was used to assess each shoulder to rule out radiographic signs of glenohumeral arthritis. After dissection, the articular surfaces, capsular tissues, and rotator cuff musculature were examined. Gross evidence of full thickness cartilage loss, visible rotator cuff tears, or evidence of prior surgery material resulted in elimination of the specimen.

Cadaveric specimens were prepared following the protocol previously described by Hartzler et al.[12] The upper extremities were prepared by cutting the arm at the mid-humerus below the deltoid insertion. A fiberglass intramedullary rod was placed into the remaining humeral shaft and secured with cross pins. Cadaveric heads were removed at a level to preserve the cervical vertebrae and the origin of the upper trapezius muscle. Solid organs were removed from the chest and abdominal cavities. Musculature originating or inserting from the spine, pelvis, sternum, ribcage, thorax, back, and shoulder girdle was otherwise preserved.

Table I Results of internal rotation moment arms (IRMAs) with the arm placed at 0° and at 90° of abduction with and without a reverse shoulder arthroplasty

Testing condition	PM-SSC	LD-SSP	LD-SSC	TM-SSP	TM-SSC
Native shoulder					
IRMA at 0° of abduction	7.1 ± 0.9	7.3 ± 1.2	5.8 ± 0.9	14.1 ± 3.1	4.2 ± 0.8
IRMA at 90° of abduction	5.5 ± 1.2	30 ± 5.4	10.3 ± 2.4	28.4 ± 6.6	8.2 ± 1.1
Reverse shoulder arthroplasty					
IRMA at 0° of abduction	19.9 ± 6.4	2.9 ± 0.5	1.6 ± 0.3	0.8 ± 0.7	4.7 ± 0.9
IRMA at 90° of abduction	22 ± 7.4	31.8 ± 11.2	7.7 ± 2.7	26.2 ± 7.8	14.4 ± 5.7

Results are given in mm for the 5 tendon-transfer pairs tested in the study.
Transferred muscles included sternal head of the pectoralis major (PM), latissimus dorsi (LD), and teres major (TM). Insertion sites included supraspinatus (SSP)—anterior part of the insertion site of the supraspinatus tendon on the greater tuberosity; and subscapularis (SSC)—insertion site of the subscapularis on the lesser tuberosity.

Skin and subcutaneous tissues were removed to allow direct visualization of the underlying shoulder and periscapular musculature. Each specimen was secured to the custom positioner used in our previous publication.[12] The specimens' native lordotic and kyphotic curvatures were preserved during the fixation of the spinal column to the custom positioner.

The Polhemus Fastrak (Colchester, VT, USA) 3-dimensional electromagnetic tracking system was used to capture raw kinematic data. This system uses sensors that can be fixed to a cadaveric specimen. These sensors are tracked by a small electromagnetic field for changes in position and orientation with 6° of freedom. Sensors were fixed to the scapula, humerus, and thorax. A coordinate system was then established according to International Society of Biomechanics according to the recommendations for each bone. Euler angles were measured to determine glenohumeral joint angles. The humeral coordinate system was modified as previously described, using the ends of the cross-pin placed perpendicular to the bicipital groove to recreate the epicondylar axis distally on the intramedullary rod.

Tendon and joint displacement (TJD) measurements were used to calculate the moment arm (MA).[2]

The humeral rod was controlled using a guide that allowed for the execution of precise passive translations and rotations in all planes. One surgeon manipulated each humerus specimen for all TJD experiments (J-DW).

Reverse shoulder arthroplasty

For the RSA configuration testing, a reverse shoulder prosthesis (Comprehensive; Zimmer-Biomet, Warsaw, IN, USA) was implanted by an experienced surgeon through a deltopectoral approach. The tenotomy of the SSC was performed. The humerus was cut in 20° retroversion at the anatomic neck. A 36 mm glenosphere was used in female cadavers and a 40 mm glenopshere used for male cadavers. This system has 5.2 mm of built-in lateralization with the use of the standard glenopsheres. The smallest polyethylene tray was used on the humeral side.[25] The SSC was not repaired at the end of the procedure to simulate an SSC deficiency.

Modeling of the tendon transfers

All tendon transfers for this study were modeled to replicate the options available in clinical practice. Transferred muscles included the sternal head of the PM, LD, and TM. These muscles were modeled to insert into 2 selected locations:

- Supraspinatus (SSP): anterior part of the insertion site of the SSP tendon on the greater tuberosity
- Subscapularis (SSC): insertion site of the SSC on the lesser tuberosity

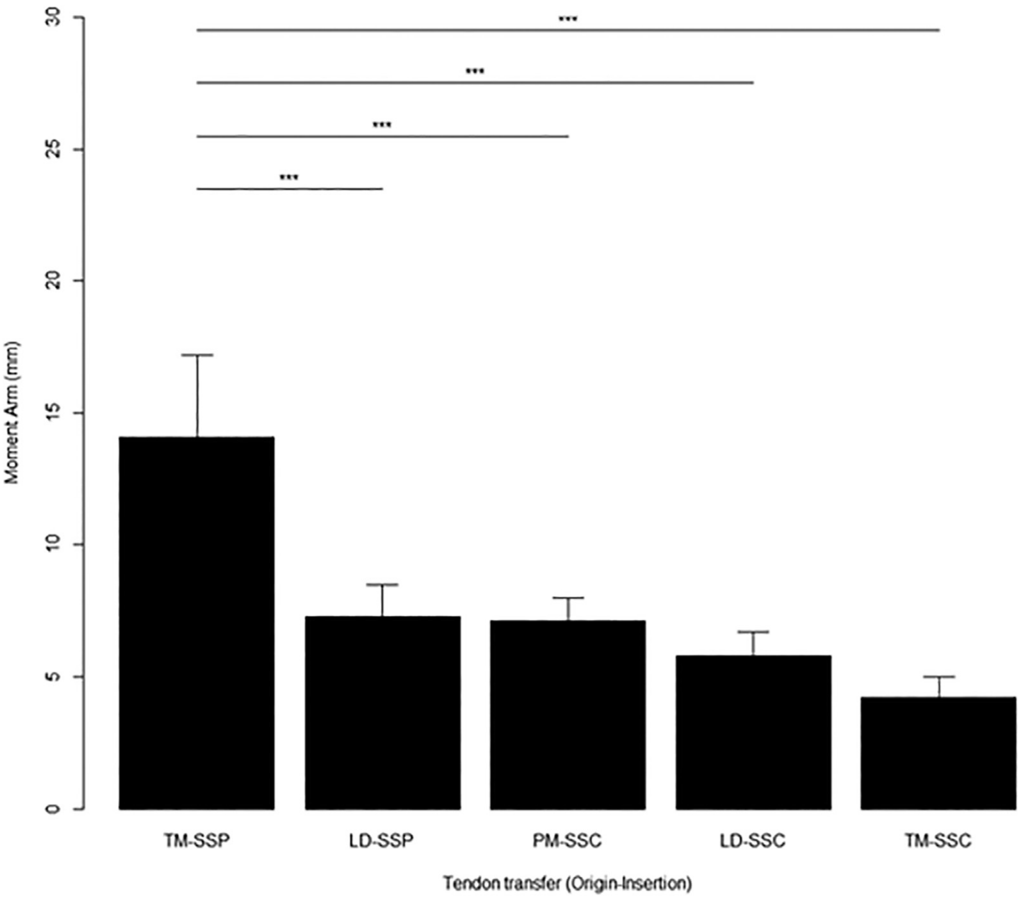

Figure 3 Internal rotation moment arm data for the tendon transfers in a native shoulder with the arm in adduction are shown as mean and standard deviation (error bars). Statistically significant differences: $***P < .001$. *TM-SSP*, teres major-supraspinatus; *LD-SSP*, latissimus dorsi-supraspinatus; *PM-SSC*, pectoralis major-subscapularis; *LD-SSC*, latissimus dorsi-subscapularis; *TM-SSC*, teres major-subscapularis.

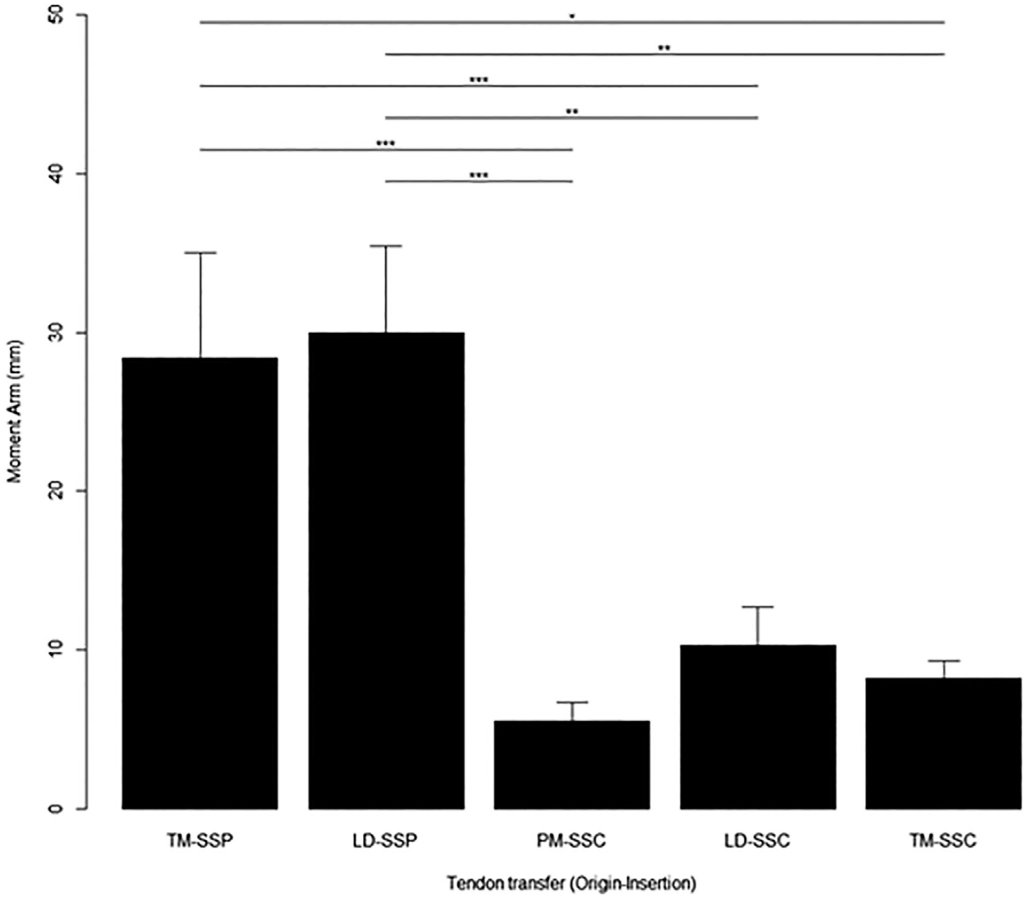

Figure 4 Internal rotation moment arm data for tendon transfers in a native shoulder with the arm in 90° scapular plane abduction are shown as mean and standard deviation (error bars). Statistically significant differences: $*P < .05$, $**P < .01$, $***P < .001$. *TM-SSP*, teres major-supraspinatus; *LD-SSP*, latissimus dorsi-supraspinatus; *PM-SSC*, pectoralis major-subscapularis; *LD-SSC*, latissimus dorsi-subscapularis; *TM-SSC*, teres major-subscapularis.

Therefore, 5 tendon-transfer pairs were modeled: PM-SSC, LD-SSP, LD-SSC, TM-SSP, and TM-SSC.

Tendon transfers were modeled by placing nonabsorbable braided #5 sutures along the line of action of the transferred muscles from its origin to insertion (Fig. 2). Each suture was centered at the muscle origin midpoint as measured by the curvilinear distance of each muscle's bony origin. The midpoint of the origin was marked and a drill hole/eye screw placed to allow passage of a cord. The PM, LD, and TM muscle tissue was then removed to allow the cord to track over the underlying structures similar to the native muscle. The cord construct used to evaluate the PM transfer was passed under the conjoined tendon when tested on the intact shoulder and above the conjoined tendon when tested with an RSA because of the risk of insufficient space for proper gliding of the transferred PM in a reverse setting.

IRMA determination

TJD experiments were performed on all specimens to model every tendon transfer variation. Joint displacement and tendon excursion were assessed throughout the arc of axial humeral rotation with the humerus at 0° of abduction for each tendon transfer. The humerus was then repositioned to 90° of abduction in the plane of the scapula. Tendon excursion and joint displacements were again assessed through an arc of axial humeral rotation. Experimental conditions were performed in triplicate to allow for conditioning of the residual soft tissues. The average MA from each of the 3 trials was used for statistical analysis.

IRMAs were computed based on the observed joint and tendon displacement. Tendon excursion is a function of both MA and joint rotation. The instantaneous MA (r) is related to tendon excursion (E) as well as joint rotation (θ) ($r = dE/d\theta$).

Axial rotation of the humerus was computed with Euler angles, which were captured from the experimental sensors. Custom electro-potentiometers were used to measure tendon excursion. Both tendon excursion and joint displacement measurements were captured using Motion Monitor Software. These data points were plotted to fit a polynomial function using Matlab software (Mathworks Inc., Natick, MA, USA), with a requirement that the root-mean-square error be <0.5 mm. The instantaneous IRMA for a specified arc of rotation of the humerus was computed at every 1°.

Statistical analysis

Tendon transfer IRMAs were compared using a 2-way repeated-value analysis of variance. Means and standard deviations of the IRMAs of the tendon pairs are reported with the arm at the side and with the arm abducted at 90°. A 2-way repeated-measures analysis of variance model was used to compare tendon transfers, position of the arm, and IRMA. The level of significance was set at $P < .05$. All statistical analyses were performed using JMP (SAS Institute Inc., Cary, NC, USA).

Results

Native shoulder

(Table I) Tendon transfers were shown to have a significant effect on IRMA ($P < .001$). With the humerus adducted (Fig. 3), the IRMA of the TM-SSP (14.1 mm ± 3.1 mm) was significantly greater than the IRMA of the LD-SSP (7.3 mm ± 1.2 mm; $P < .001$) or PM-SSC (7.1 mm ± 0.9 mm; $P < .001$). With the humerus abducted to 90° (Fig. 4), the IRMAs of the LD-SSP (30.0 mm ± 5.4 mm) and TM-SSP (28.4 mm ± 6.6 mm) were significantly greater than the IRMA of the LD-SSC (10.3 mm ± 2.4 mm; $P = .03$, $P = .007$) or TM-SSC (8.2 mm ± 1.1 mm; $P = .001$, $P = .04$) or PM-SSC (5.5 mm ± 1.2 mm; $P < .001$, $P < .001$).

The effect of transferred tendons was significantly affected by the position of the humerus ($P < .0001$). With the shoulder at 90° of abduction, the IRMAs of the LD-SSP (30.0 mm ± 10.1 mm) and TM-SSP (28.4 mm ± 7 mm) were significantly greater than the IRMA with the humerus adducted to 0° (LD-SSP: 7.3 mm ± 1.4 mm, $P = .004$; TM-SSP: 14.1 mm ± 2.9 mm, $P = .03$). However, the IRMAs of the PM, LD-SSC, and TM-SSC remained relatively unaffected by the position of the humerus in abduction-adduction.

Reverse shoulder arthroplasty

When tendon transfers were performed in conjunction with RSA, tendon transfers also significantly affected the evaluated IRMA ($P < .0001$). With the humerus adducted to the side (Fig. 5), the IRMA of the PM-SSC (19.9 mm ± 6.4 mm) was significantly greater than the IRMA of the TM-SSC (4.7 mm ± 0.9 mm; $P < .001$) or LD-SSP (2.9 mm ± 0.5 mm; $P < .001$). With the humerus abducted to 90° (Fig. 6), the IRMAs of the LD-SSP (31.8 mm ± 11.2 mm), TM-SSP (26.2 mm ± 7.8 mm), and PM-SSC (22 mm ± 7.4 mm) were not significantly different. However, the

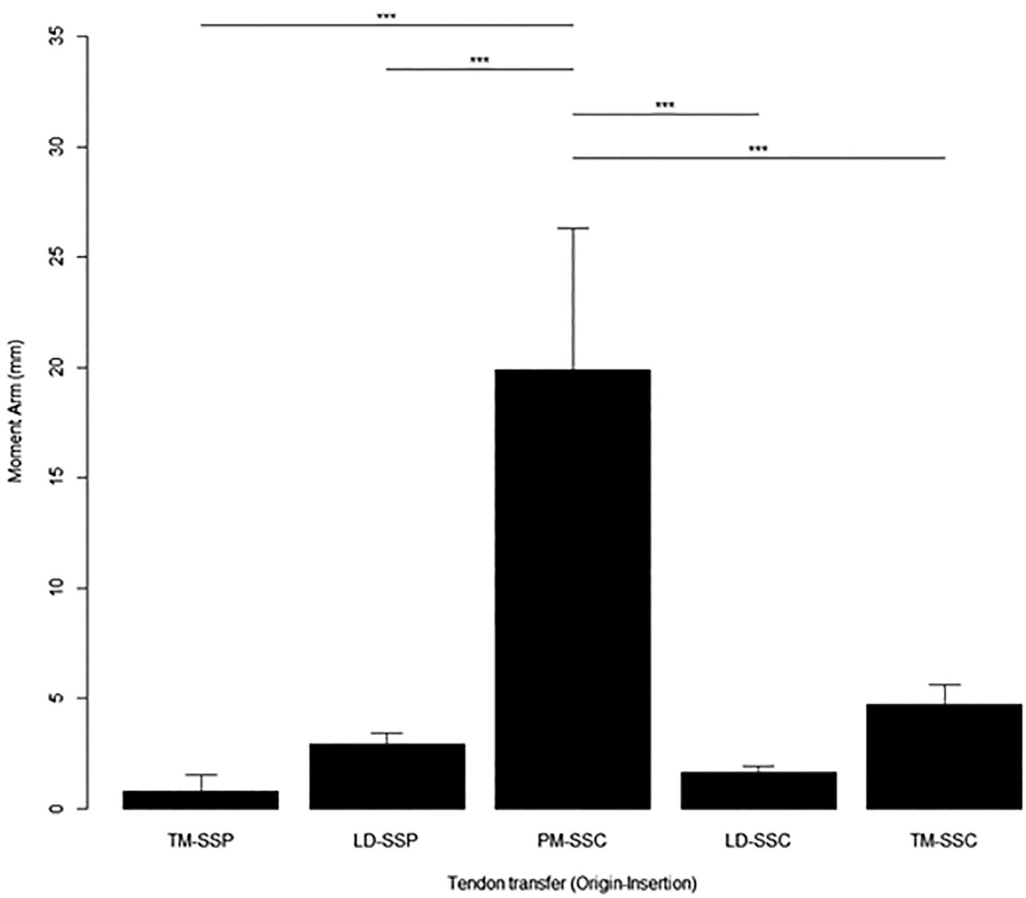

Figure 5 Internal rotation moment arm data for the tendon transfers combined with a reverse shoulder arthroplasty with the arm in adduction are shown as mean and standard deviation (error bars). Statistically significant differences: * * * $P < .001$. *TM-SSP*, teres major-supraspinatus; *LD-SSP*, latissimus dorsi-supraspinatus; *PM-SSC*, pectoralis major-subscapularis; *LD-SSC*, latissimus dorsi-subscapularis; *TM-SSC*, teres major-subscapularis.

IRMAs of the TM and LD transfers were significantly smaller when transferred to the SSC than to the SSP (14.4 mm ± 5.7 mm vs. 26.2 mm ± 5.8 mm, $P = .05$ and 7.7 mm ± 2.7 mm vs. 31.8 mm ± 10.1 mm, $P = .043$, respectively).

The IRMA of the native shoulder differed significantly from that of the RSA state for all tendon transfers ($P < .0001$). With the humerus adducted to the side of the body (Fig. 7), the IRMA of the RSA PM-SSC transfer was significantly greater than without an RSA ($P < .0001$), demonstrating increased efficiency for internal rotation in the RSA state. In contrast, the IRMA of the TM-SSP was more advantageous in the native shoulder, with a significantly greater IRMA compared with the same tendon transfer after implantation with an RSA ($P < .0001$). The IRMA of the LD-SSP remained relatively unchanged before and after RSA ($P = .09$). With the shoulder abducted to 90° (Fig. 8), the IRMA of the PM-SSC with an RSA was significantly greater compared with a native shoulder ($P < .0001$), whereas the IRMAs of the LD-SSP and the TM-SSP were similar in both conditions ($P = .12$ and $P = .09$, respectively).

Discussion

This biomechanical study shows that in a native shoulder, the transfer of the TM and of the LD proximally to the anterior footprint of the SSP could efficiently restore active internal rotation, especially when the arm is abducted. In this position, the line of pull of the LD is directly perpendicular to the axis of rotation of the humerus. Internal rotation with the arm abducted is crucial to placing the arm behind the back, which is necessary for personal hygiene.[15,24]

The feasibility of transferring the TM and LD has been evaluated in a cadaveric study.[7] Further work by Elhassan et al[7] showed that the LD can be transferred anteriorly without risking impingement of the axillary or radial nerve. However, the transfer of the TM may possibly lead to compression of the axillary nerve within the quadrangular space. Therefore, the safest and most effective option to restore the internal rotation motion arm after an irreparable tear of the SSC is the transfer of the LD proximally on the humeral head at the level of the anterior footprint of the SSP.

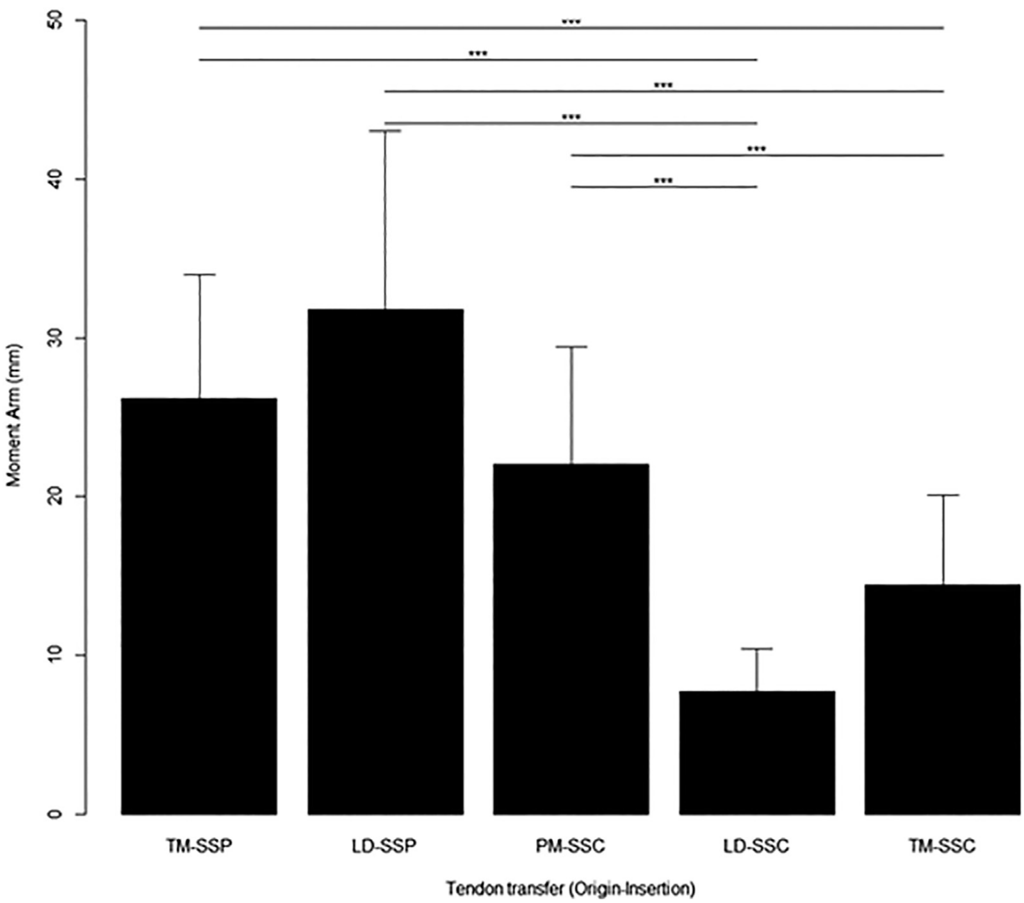

Figure 6 Internal rotation moment arm data for tendon transfers combined with a reverse shoulder arthroplasty with the arm in 90° scapular plane abduction are shown as mean and standard deviation (error bars). Statistically significant differences: $***P < .001$. *TM-SSP*, teres major-supraspinatus; *LD-SSP*, latissimus dorsi-supraspinatus; *PM-SSC*, pectoralis major-subscapularis; *LD-SSC*, latissimus dorsi-subscapularis; *TM-SSC*, teres major-subscapularis.

This is supported by recent clinical studies[14,18] showing a statistically significant improvement in internal rotation from L5 to L1 in 29 patients after the transfer of the LD anteriorly to the proximal portion of the lesser tuberosity.

Long-term follow-up studies on the transfer of the sternal head of the PM below the conjoined tendon for irreparable tear of the SSC have reported satisfactory long-term results.[9,17] In these studies, the indication for surgery was pain and loss of motion. At a mean follow-up (19.7 years and 10 years, respectively), the authors of both studies showed significant improvement in pain and range of motion (including internal rotation) after the PM transfer. However, it is important to note that none of the patients complained of anterior instability before transfer. Unsatisfactory results after the transfer of the pectoralis tendon have been reported when patients have concurrent anterior instability or subluxation.[8,19]

Our biomechanical study shows that the IRMA of the PM transfer is inferior to that of the TM with the arm on the side and both the TM and LD with the arm at 90° of abduction when tested in the native shoulder. This is due to the fact that the native shoulder is an unconstrained joint and transferring the PM causes the head to translate anteriorly rather than purely internally rotate. The PM transfer is able to restore internal rotation when the arm is placed in maximum external rotation, but as soon as the arm moves to neutral rotation, the transfer is no longer efficient. Anterior translation may be accentuated in patients with concurrent loss of the anterior labrum and deficient glenohumeral ligaments. In patients without prior instability or subluxation, the native tissues may continue to provide resistance to instability and allow the pectoralis tendon to provide an anterior compressive force to counterbalance the intact posterior rotator cuff. With loss of the anterior labrum, the transfer of the pectoralis tendon may cause anterior subluxation and destabilize the centered compressive force to the glenohumeral joint. Therefore, in younger patients with a history of shoulder instability and an irreparable SSC, an LD transfer may be the preferred transfer to restore a posteriorly directed line of pull to avoid an anteriorly directed transfer force. Further studies are necessary to evaluate the effect of the anterior labrum in the setting of tendon transfers for irreparable anterior rotator cuff tears.

However, the biomechanics of this transfer does change after RSA. The RSA is a semiconstrained prosthesis, and

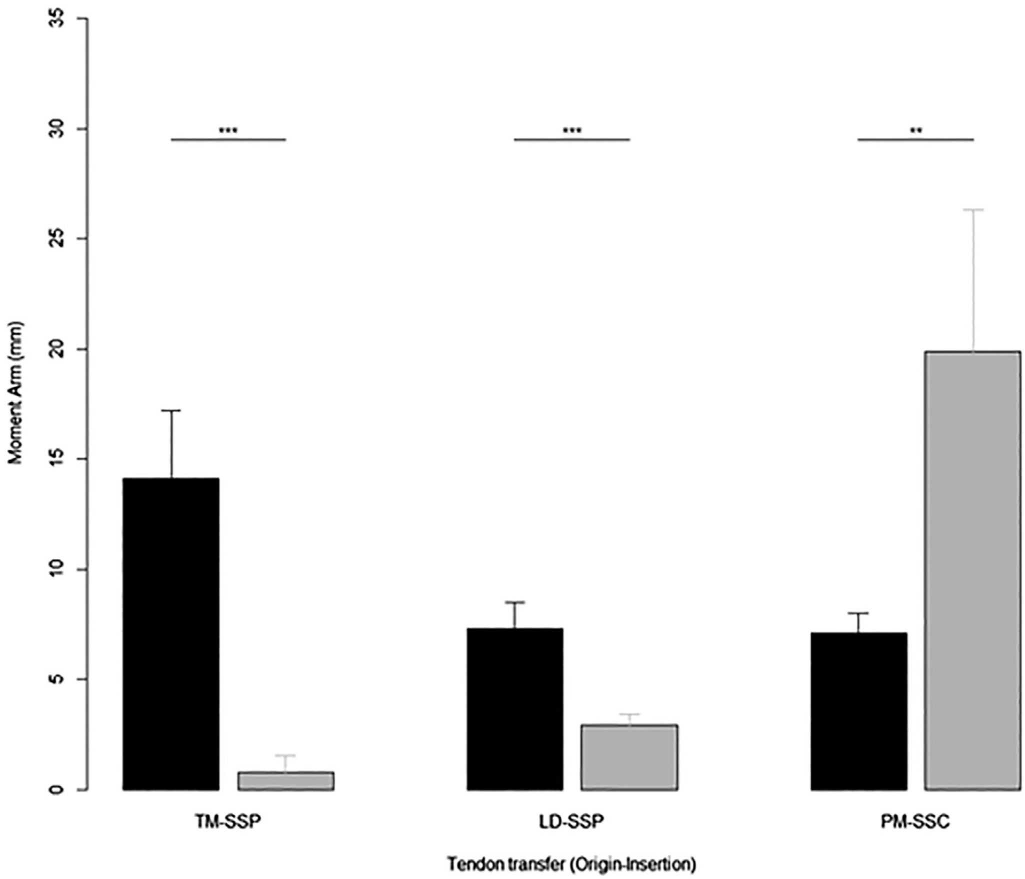

Figure 7 Internal rotation moment arm data for the tendon transfers without (black) and with a reverse shoulder arthroplasty (gray) with the arm in adduction are shown as mean and standard deviation (error bars). Statistically significant differences: $**P < .01$, $***P < .001$. *TM-SSP*, teres major-supraspinatus; *LD-SSP*, latissimus dorsi-supraspinatus; *PM-SSC*, pectoralis major-subscapularis.

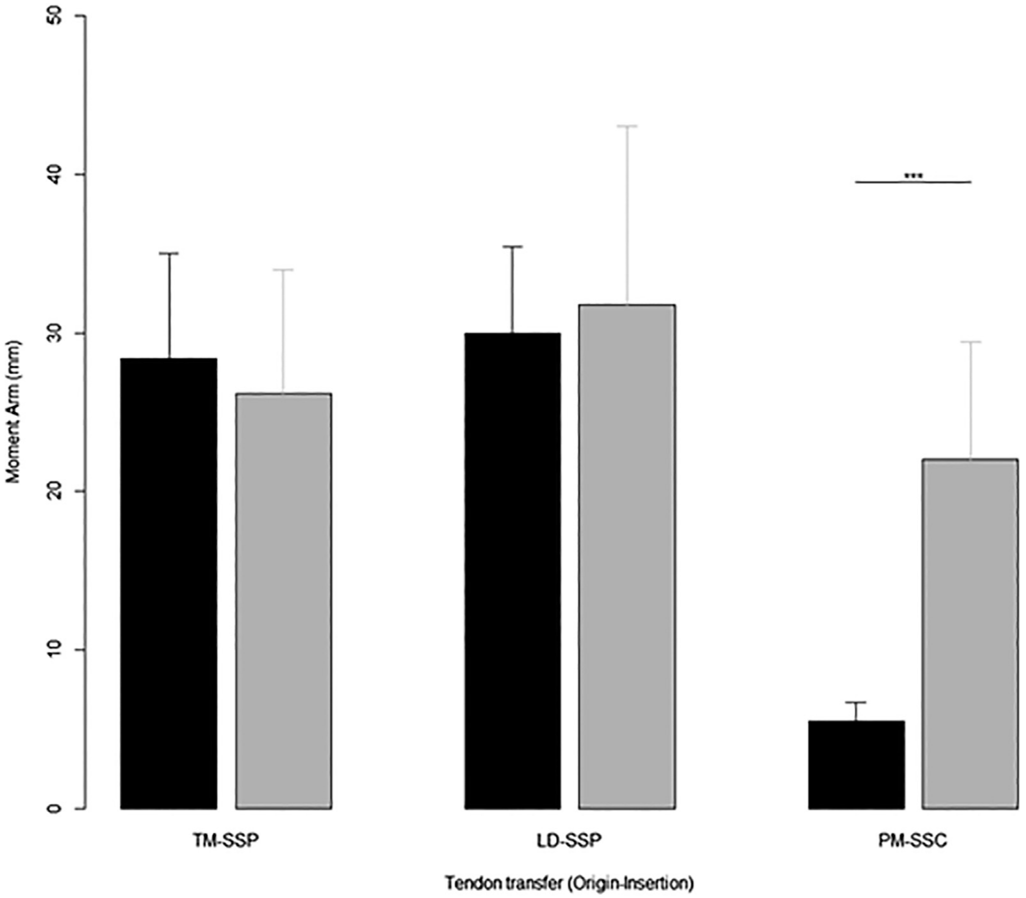

Figure 8 Internal rotation moment arm data for tendon transfers without (black) and with a reverse shoulder arthroplasty (gray) with the arm in 90° scapular plane abduction are shown as mean and standard deviation (error bars). Statistically significant differences: $***P < .001$. *TM-SSP*, teres major-supraspinatus; *LD-SSP*, latissimus dorsi-supraspinatus; *PM-SSC*, pectoralis major-subscapularis.

the humeral head does not translate anteriorly. Instead, all applied forces are converted into rotational forces. Thus, the transfer of the sternal head of the PM becomes an efficient transfer to restore internal rotation. Several hypotheses have been proposed to explain the loss of internal rotation after RSA. These include rotator cuff deficiency, alteration of the rotator cuff MA, poor scapulothoracic control, and mechanical impingement. Of these, the most commonly accepted explanation is that excessive medialization creates mechanical impingement between the scapular pillar and the humerus and decreases the tension of the residual rotator cuff.[3] This mechanical impingement has been confirmed by Rol et al[21] as they have proven that postoperative internal rotation above L3 was significantly associated with a greater glenosphere overhang. In the Rol et al series[21] with no glenoid lateralization (which could possibly decrease impingement between the humerus and scapular pillar), neither the condition of the SSC nor SSC repair was significantly associated with improved internal rotation. However, Collin[5] showed that internal rotation in patients with a healed SSC tendon was significantly higher than that in the patients with a ruptured repair after RSA with a lateralized glenosphere configuration. Therefore, the transfer of the PM tendon may be an option to restore active internal rotation in combination with a lateralized glenosphere RSA when the SSC is irreparable. This transfer can easily be performed through a deltopectoral approach by detaching the insertion from the lateral border of the bicipital groove and transferring it to the lesser tuberosity. Clinical studies are needed to confirm this hypothesis.

This biomechanical study is limited by several factors. First, IRMAs were determined only for glenohumeral internal rotation. Clinically, internal rotation is the result of combined motions of both the glenohumeral joint and the scapulothoracic articulation. On the basis of this model, we are unable to assess the effect of these tendon transfers when the scapula is not a fixed structure. Second, the IRMA was only calculated for the transferred tendon. This did not take into account the volume of the muscle generating the force, which can affect the IRMA. In addition, this study was limited to a small number of cadaveric specimens, which may have affected the results. Because of these limitations, the number of variables evaluated in our statistical model was limited to comparing tendon transfer pairs that were deemed to be clinically relevant. Third, the transferred muscles each have broad origins. The simplification of reproducing the line of pull from the center of the muscular origin may not replicate the in vivo function of these tendon transfers. However, we felt this was necessary to simplify the comparisons and maintain clinically meaningful results. Lastly, the effects of the surgical technique, tendon mobilization, length-tension relationships, and glenohumeral stability were not addressed with this model. Even with these limitations, the observed differences between transfers were great enough to achieve statistical significance using a modeling strategy that accounted for repeated measures. This study should serve as a foundation for future biomechanical studies on the effect of tendon transfer to restore internal rotation to the glenohumeral joint.

Conclusion

Tendon transfers to restore shoulder internal rotation differ in effectiveness and may be affected by arm position and by implantation of RSA. The LD potentially results in superior restoration of shoulder internal rotation in a native shoulder (given the risk of nerve compression with the TM transfer) compared with the PM and should be considered as a potential tendon transfer to restore internal rotation in selected patients. In combination with an RSA, the fulcrum provided by the biomechanics of the semiconstrained implant allows the PM transfer to become a more efficient tendon transfer to restore active internal rotation.

Disclaimer

Jean-David Werthel is a paid consultant for and receives royalties from FH Orthopedics.

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