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Latissimus dorsi tendon transfer in reverse shoulder arthroplasty: transfer location affects strength



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Background: The optimal insertion location of a latissimus dorsi tendon transfer to restore external rotation after reverse shoulder arthroplasty (RSA) is not well established. The aim of this biomechanical study was to determine the effect of tendon transfer location on external rotation torque, in conjunction with varying RSA humeral component lateralization. We hypothesized that proximal tendon transfers, along with increasing humeral lateralization, would maximize external rotation torque.

Methods: Eight fresh-frozen cadaveric shoulders underwent RSA and were tested on an in vitro shoulder simulator. A latissimus dorsi tendon transfer was tested at three insertion locations (lateral greater tuberosity [Lat-GT]; teres minor footprint [Tm-FP]; lateral shaft [Lat-Shft]), and external rotation torque was measured. Additional test conditions included varying humeral component lateralization (-5, 0, +5, +10, +15 mm), abduction angle (0°, 45°, 90°), and internal/external rotation (-60°, -30°, 0°, 30°, 60°). **Results:** The Lat-GT and Tm-FP insertions of the latissimus dorsi transfer both generated significantly greater torques ($P < .001$) than the Lat-Shft. When comparing Lat-GT to Tm-FP, there were no significant differences ($P = .362$). At 60° of external rotation, RSA humeral component lateralization from -5 to +15 mm significantly increased the external rotation torque of Lat-GT by 67% ($P = .035$), Tm-FP by 43% ($P = .001$), and of Lat-Shft by 42% ($P = .002$).

Conclusion: Latissimus dorsi tendon transfer to the proximal lateral aspect of the greater tuberosity and to the insertion site of the teres minor generated significantly more external rotation torque than transfer to the lateral humeral shaft. In addition, the use of a humeral component with greater offset also substantially increases the torque generated by the tendon transfer.

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Reverse total shoulder arthroplasty (RSA) is an effective treatment for improving active forward elevation, pain relief, and function secondary to symptomatic rotator cuff tear arthropathy. RSA, however, is less predictable in improving active external rotation in patients with a deficient infraspinatus and teres minor. As such, the addition of a latissimus dorsi tendon transfer has been described with good outcomes.^{1–4,7,8,14,15} In addition to tendon transfer, other strategies to improve active external rotation strength include adjusting humeral component neck-shaft angle and offset.^{5,10,11}

At present, little clinical or biomechanical cadaveric studies exist on the ideal location of tendon transfer insertion to optimize

external rotation of the shoulder. Common locations include the lateral aspect of the bicipital groove, the posterolateral aspect of the greater tuberosity, the teres minor insertion, the upper half of the pectoralis major insertion footprint, the original footprint of the latissimus dorsi insertion, and other nonspecific sites either anterior, posterior, or inferior to the greater tuberosity.^{3,4,6–8,10–14} The effect of these locations on external rotation torque remains largely unknown. Torque is the appropriate metric to quantify the effect of a tendon transfer for external rotation, as it is a measure of the force that can cause an object (the humerus) rotate about its axis (active external rotation). Therefore, the purpose of this in vitro biomechanical cadaveric study was to evaluate the effect of varying latissimus dorsi tendon transfer location on external rotation torque, in conjunction with varying lateralization of the RSA humeral component. We hypothesized that transfer sites that increased the external moment arm would result in greater external rotation torque produced by the latissimus dorsi transfer, whereas humeral lateralization would further increase torque of each transfer.

Institutional review board approval was not required for this basic science study. Investigations performed at the Bioengineering Laboratory at the Roth/McFarlane Hand and Upper Limb Center, London, ON, Canada.

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Materials and methods

Specimen preparation and shoulder simulation

Eight fresh-frozen human cadaveric shoulders without pre-existing glenohumeral arthritis or rotator cuff tears were examined. The shoulders were transected at the mid-humerus, and the deltoid, rotator cuff muscles, and glenohumeral joint capsule were identified through dissection. The entire posterosuperior rotator cuff was released off the proximal humerus. The subscapularis tendon insertion was maintained and to access the joint for reverse arthroplasty, the subscapularis muscle was reflected laterally off the anterior aspect of the scapular body. By reflecting the subscapularis in this manner, the joint could be repeatedly accessed without disrupting the subscapularis tendon. The tendinous insertions of the pectoralis major and trapezius were preserved. A custom RSA (Fig. 1) was implanted as per standard technique, with the humeral component cemented in 20° of retroversion. The specimens were then mounted on an in vitro shoulder simulator,⁹ and all remaining muscles (anterior, middle and posterior deltoid, subscapularis, latissimus dorsi, teres major, and pectoralis major) were connected to computer-controlled pneumatic actuators along physiologically accurate lines of action (Fig. 2). To minimize tendon creep over the testing period, tendons were reinforced with high strength suture. An intramedullary rod was cemented into the shaft of the humerus, with a 6 degree-of-freedom Mini45 load cell (ATI, Apex, NC, USA) interposed between the proximal rod and the distal rod used to measure torques.

Custom adjustable RSA

The amount of humeral lateralization was varied using a custom in-lay modular humeral component that could be adjusted.^{5,9} The implant had a 145° head-neck angle and a 12-mm lateral offset

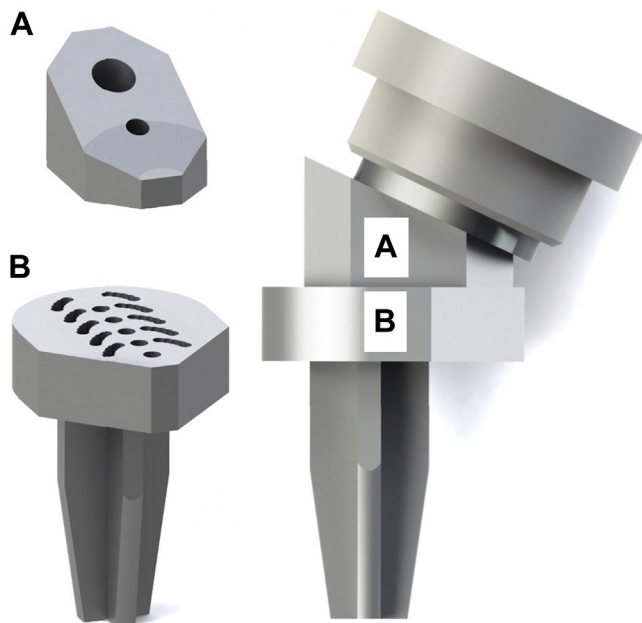


Figure 1 A custom modular reverse total shoulder arthroplasty humeral implant was designed that would allow incremental adjustment of humeral offset. The neck shaft angle was set at 145 degrees (A). The neutral (0) offset was set at 12 mm. The neck shaft angle component (A) could be translated on the metaphyseal component (B) 5 mm medial, and 5, 10, and 15 mm lateral. This allowed testing of absolute humeral offsets of 7 (-5), 12 (0), 17 (+5), 22 (+10), and 27 (+15) mm, which corresponds to the complete range of commercially available¹⁵ humeral components.

(referred to as neutral) between the cup and the humeral stem. The humeral offset could be adjusted to five offsets from the neutral (12mm) position: -5mm medial, 0, +5, +10, and +15 mm lateral, which would encompass all commercially available humeral implant offsets.¹⁵ Therefore, the absolute offsets of the modular humeral implant tested were 7, 12, 17, 22, and 27 mm. The glenosphere was inserted in the neutral position with the center of rotation located at the glenoid articular surface.

Experimental protocol and statistics

The latissimus dorsi tendinous insertion was released, and examined in a randomized manner in three transfer locations (Fig. 3):

- i) *Lat-GT*: the lateral upper most aspect of the greater tuberosity
- ii) *Tm-FP*: the teres minor foot print
- iii) *Lat-Shft*: the lateral aspect of the proximal humeral shaft opposite the original insertion

All tendon transfers were performed using transosseous sutures. In each trial, 5N tone loads were applied to the three deltoid muscles and 24N was applied to the latissimus dorsi muscle.^{5,9} A total of 21 shoulder positions were evaluated for each tendon transfer in a randomized manner, based on combinations of two parameters: (1) scapular plane abduction in 0°, 45°, and 90°, and (2) humeral rotation. Humeral rotation was assessed at neutral (0°), at -30° and -60° of internal rotation, and at 30° and 60° of external rotation. In each position, the implanted humeral component was tested in five variations of humeral lateralization offset: -5, 0, +5, +10, and +15 mm.

Each configuration was tested three times, and the mean rotational torque value was used. A repeated-measures ANOVA with a Bonferroni correction was used to determine statistical significance ($P < .05$) for the independent variables of tendon transfer location, abduction angle, internal-external rotation and implant position, and dependent variable of output torque.

Results

External rotation torque

The *Lat-GT* and the *Tm-FP* insertion points of the latissimus dorsi tendon transfer both generated significantly greater torques ($P < .001$) than the *Lat-Shft*. The *Lat-GT* generated a mean of 1.8 ± 0.2 Nm greater torque than the *Lat-Shft* ($P < .001$), whereas the *Tm-FP* generated a mean of 1.5 ± 0.1 Nm greater torque than the *Lat-Shft* ($P < .001$). When comparing the *Lat-GT* to the *Tm-FP*, there were no significant differences in the torque generated ($P = .362$).

Abduction angle

As abduction angle increased, the external rotation torque generated from all tendon transfer locations significantly decreased ($P \leq .021$). External rotation torque significantly decreased from 0° to 45° of abduction ($P = .002$) and from 45° to 90° ($P = .021$) of abduction. Overall, external rotational torque for all tendon transfers was greatest at 0° (Fig. 4).

Internal/external rotation angle

The external rotation torque of the glenohumeral joint increased proportionately with the degree of external rotation ($P < .001$, Fig. 4). At 0° abduction, as the arm was brought from 60° internal

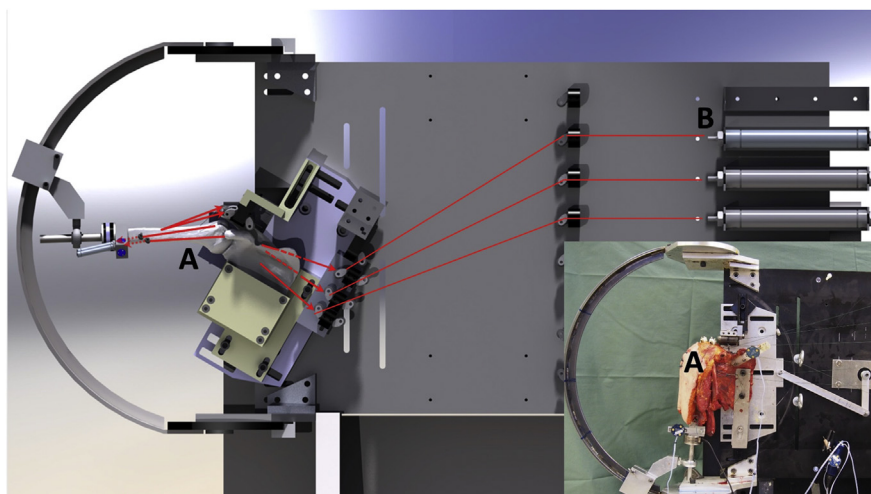


Figure 2 An illustration of the shoulder simulator utilized to test the latissimus dorsi tendon transfer [inset: cadaveric specimen attached to the simulator]. (A) Cadaveric specimen; (B) actuators used to load the rotator cuff, deltoid, and latissimus dorsi.

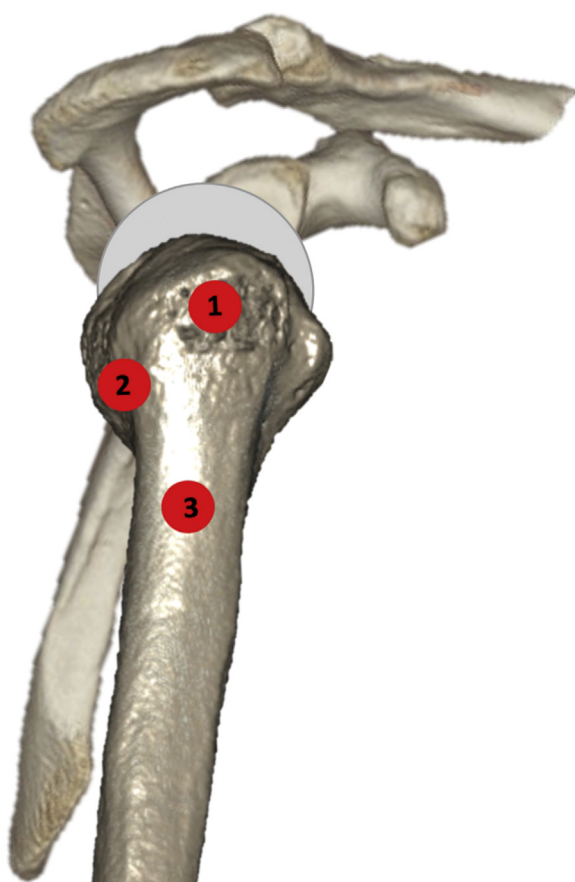


Figure 3 The tendon transfer was tested at three insertion points with a reverse shoulder arthroplasty. Location #1 represents the proximal lateral aspect of the greater tuberosity (Lat-GT: lateral greater tuberosity); location #2 represents the insertional footprint of the teres minor (Tm-FP); and location #3 represents the lateral aspect of the proximal humeral shaft (Lat-Shft) across from the native insertion site of the latissimus dorsi.

rotation to 60° external rotation, Lat-Shft torque increased by $4.4 \pm 1.0\text{Nm}$ ($P < .001$), Tm-FP torque increased by $5.2 \pm 1.7 \text{ Nm}$ ($P < .001$), and Lat-GT torque increased by $4.6 \pm 2.3 \text{ Nm}$ ($P < .001$). The Tm-FP and Lat-Shft transfers showed significant increases in

torque between each rotational position ($P < .02$), whereas the Lat-GT transfer only had significant increases from -30° to 0 and 0 to 30° ($P < .02$).

Comparing torque between transfer locations at each rotation angle, Lat-GT and Tm-FP had significantly more torque than Lat-Shft in every rotation angle at 0°, 45°, and 90° of abduction ($P < .02$, Fig. 4). Lat-GT had significantly more torque than Tm-FP only in -30° internal rotation and 90° abduction ($P = .04$), otherwise all other differences did not reach significance.

Humeral lateralization

At 0 elevation, humeral lateralization had a significant effect on tendon transfer torque at 60° IR and ER (Fig. 5, $P < .035$). At 60° of external rotation, humeral lateralization from -5 to +15 mm significantly increased the external rotation torque of the Lat-GT by $1.9 \pm 3.3 \text{ Nm}$ ($67 \pm 34\%$, $P = .035$), Tm-FP by $2.1 \pm 2.2 \text{ Nm}$ ($43 \pm 31\%$, $P = .001$), and of the Lat-Shft by $1.7 \pm 1.5 \text{ Nm}$ ($42 \pm 26\%$, $P = .002$). Please see Figure 5.

Discussion

A latissimus dorsi tendon transfer has been described as an effective adjunct to reverse total shoulder arthroplasty to improve active external rotation in patients with lag signs associated with absent infraspinatus and teres minor.^{1–4,7,8,14,15} The results of this biomechanical cadaveric study indicate that the anatomic position of the transfer has a substantial effect on the torque generated, and thereby the potential strength realized by the patient. All three tendon transfer locations (lateral greater tuberosity, teres minor footprint, and the lateral humeral shaft) resulted in active external rotation. Insertion of the latissimus tendon transfer into the lateral aspect of the greater tuberosity (Lat-GT) and into the teres minor footprint (Tm-FP) on the posterolateral aspect of the greater tuberosity resulted in significantly greater torque than transfer to the lateral aspect of the proximal humeral shaft (Lat-Shft). In addition, increasing the humeral component lateral offset also resulted in substantial increases in external rotation torque as compared to a medialized offset humeral component. As such, our hypotheses were supported.

The superior external rotation torque obtained by the Lat-GT and Tm-FP tendon transfer insertion locations makes sense.

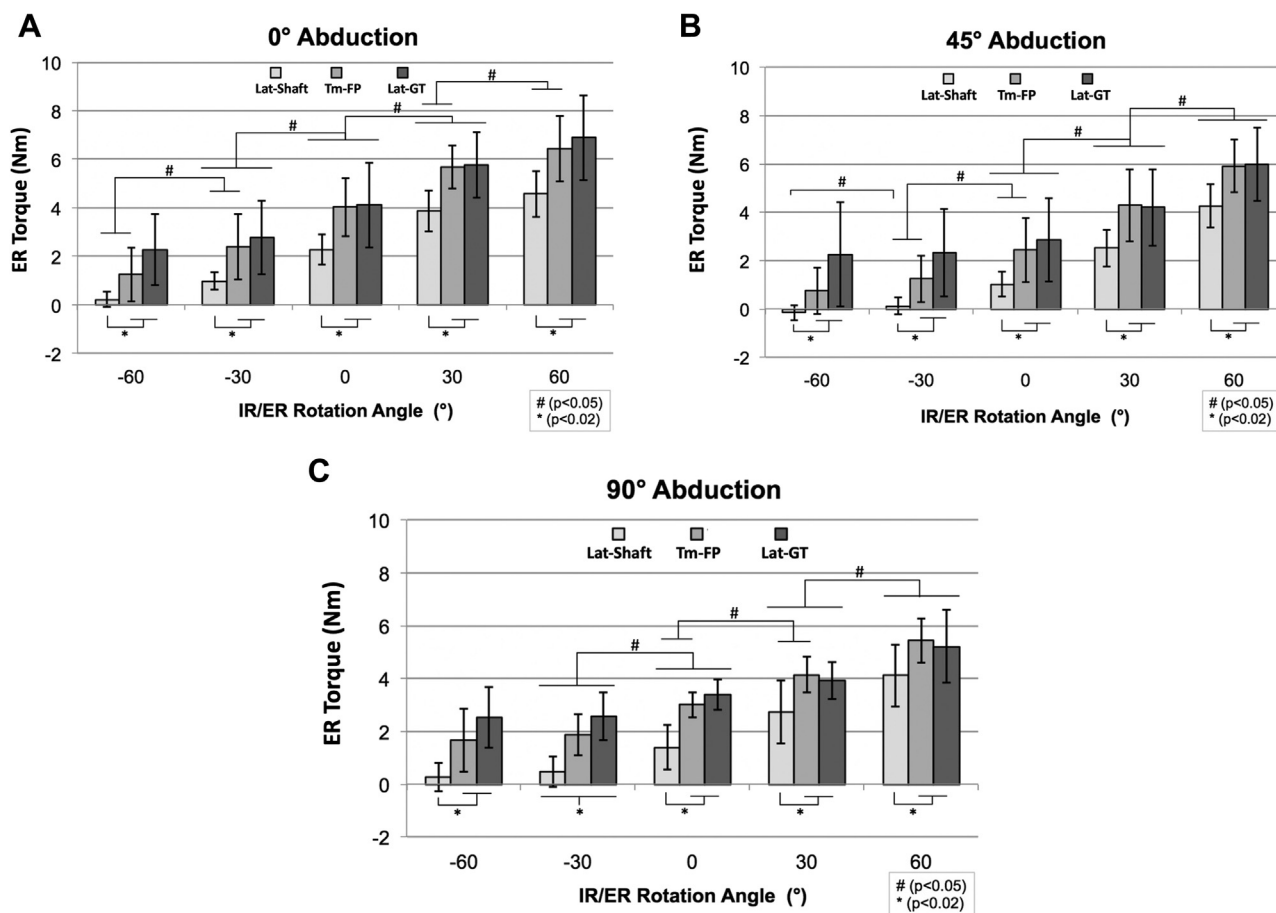


Figure 4 The mean (± 1 std dev) external rotation torque (y-axis) of the latissimus dorsi tendon transfers for 0° (A), 45° (B), and 90° (C) abduction angles moving from internal rotation (left) to external rotation (right) on the x-axis.

These insertion points allow for a greater external rotation moment arm for the transfer, as well as increasing the tendon excursion length and associated tenodesis effect. This is in agreement with the study conducted by Favre et al,⁶ who used a silicone model to calculate the moment arms produced by different insertion locations. The authors concluded that based on a moment arm calculation, the tendon site posterior to the greater tuberosity was preferred over a site inferior to the tuberosity.

Although there is little literature on RSA and tendon transfer biomechanics, several studies have been published assessing the role of tendon transfers in the management of massive rotator cuff tears.^{10,11} These studies on massive rotator cuff tears have identified the infraspinatus tendon insertion,¹⁰ or the junction of the supraspinatus and infraspinatus¹¹ as the optimal transfer sites. However, these studies examined a different disease state with a relatively unconstrained native shoulder joint. As the RSA has a higher degree of constraint, it may provide a mechanical advantage for tendon transfers to function. In addition, the studies on massive cuff tears were conducted to achieve both active forward elevation and active external rotation, while with RSA, the goal is limited to active external rotation so the transfer location may be optimized to obtain the desired effect. Finally, the studies on massive rotator cuff tears and tendon transfers were computational studies that run into the challenges of modeling tendon wrapping around bony and soft tissue structures.

Chan et al⁵ examined the effect of RSA humeral component lateralization on rotator cuff torque. Similarly, Chan et al found that

external rotation force increased as humeral lateralization increased when the arm was in external rotation. Our findings with tendon transfers to obtain active external rotation were similar. The degree of humeral rotation consistently showed an influence on the external rotation moment produced by the latissimus dorsi for each of the transfer locations. This moment was highest in external rotation due to the latissimus dorsi tendon transfer insertion site being displaced more laterally from the joint axis of rotation. It is important to note that both Lat-GT and Tm-FP were able to still produce an external moment, albeit small, in the fully internally rotated position, whereas the Lat-Shft transfer struggled to do so. The findings of the present study highlight the superiority of the Lat-GT and Tm-FP tendon transfer insertion sites in being able to provide active external rotation for many ranges of motion and positions required to conduct many activities of daily living.

Clinical outcome scores after RSA with combined latissimus dorsi transfer show modest improvements in active external rotation motion ranging from 23 to 37.^{1–4,7,8,14,15} However, tendon transfer location must also be considered based on its ability to maintain internal rotation motion and strength. Boileau et al^{1–3} initially used tendon-to-tendon fixation of the transfer to the pectoralis major tendon on the anterior aspect of the humeral shaft before changing to a lateral humeral shaft. In their initial assessments, they found a decrease in functional internal rotation after transfer to the pectoralis major insertion, possibly attributed to the more anterior transfer location causing over-tensioning and a tenodesis effect.

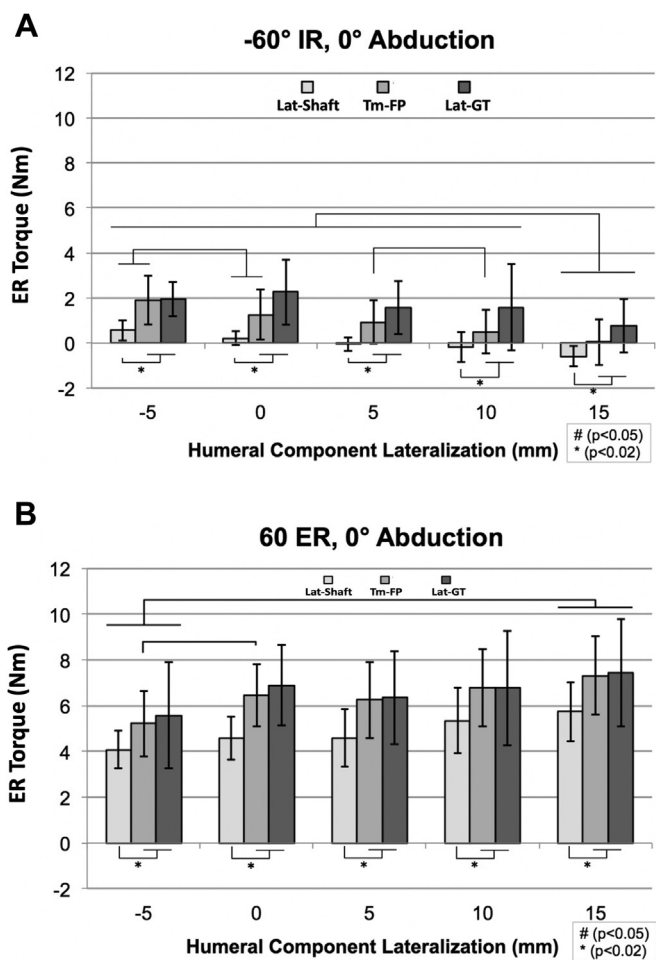


Figure 5 Mean (± 1 std dev) external rotation torque at 60° internal rotation (A) at various humeral component offsets (-5, 0, +5, +10, +15 mm) and the mean (± 1 std dev) external rotation torque at 60° of external rotation (B) at all humeral component offsets.

The present study is constrained by its biomechanical design, hence not allowing for any temporal effects of soft tissue adaptation associated with the procedure. In addition, the effects of the posterior deltoid muscle as an active external rotator were not assessed. However, the present study does contribute to the limited literature on tendon transfer location influencing external rotation torque in RSA. In addition, little research has been conducted on humeral component lateralization in RSA and its influence on tendon transfer optimization.

Conclusion

Latissimus dorsi tendon transfer has been described as an adjunct to reverse shoulder arthroplasty in some patients with complete absence of the external rotators. This biomechanical study demonstrated that the anatomic location of the tendon transfer on the proximal humerus has substantial effects on the resultant external rotation torque. Specifically, transfer to the proximal lateral aspect of the greater tuberosity and transfer to the insertion site of the teres minor generate significantly more external rotation torque than transfer to the more distal aspect of the lateral humeral shaft. In addition, the use of a humeral

component with greater offset also substantially increased the torque generated by the tendon transfer.

Disclaimer

GSA is a consultant for Wright Medical-Tornier Inc. No company had any input in the study design, protocol, testing, data analysis, or manuscript preparation.

The other authors (KC, DL, MW, JJ), 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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