Electromyographic activity after latissimus dorsi transfer: testing of coactivation as a simple tool to assess latissimus dorsi motor learning

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**Background:** The purpose of this study was to investigate coactivation (CoA) testing as a clinical tool to monitor motor learning after latissimus dorsi tendon transfer.

**Methods:** We evaluated 20 patients clinically with the American Shoulder and Elbow Surgeons (ASES) and University of California–Los Angeles (UCLA) outcomes scores, visual analog scale, active external rotation (aER), and isometric strength testing in abduction and external rotation. Measurements of aER were performed while the latissimus dorsi was activated in its new function of external rotation with concomitant activation (coactivation) of its native functions (adduction and extension). Bilateral surface electromyographic (EMG) activity was recorded during aER measurements and the strength testing procedure (EMG activity ratio: with/without CoA). Patients were divided into two groups (excellent/good vs fair/poor) according to the results of the ASES and UCLA scores.

**Results:** The mean follow-up was 57.8 ± 25.2 months. Subdivided by clinical scores, the superior outcome group lost aER with CoA, whereas the inferior outcome group gained aER (UCLA score: −2.2° ± 7.4° vs +4.3° ± 4.1°; \(P = .031\)). Patients with inferior outcomes in the ASES score showed higher latissimus dorsi EMG activity ratios (\(P = .027\)), suggesting an inadequate motor learning process. Isometric strength testing revealed that the latissimus dorsi transfer had significantly greater activity compared with the contralateral side (external rotation, \(P = .008\); abduction, \(P = .006\)) but did not have comparable strength (external rotation, \(P = .017\); abduction, \(P = .009\)).

**Conclusions:** Patients with inferior clinical results were more likely to be dependent on CoA to gain external rotation. Therefore, CoA testing may be used as a tool to evaluate the status of postoperative motor learning after latissimus dorsi transfer.

**Level of evidence:** Basic Science, Electromyography.

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**Keywords:** Latissimus dorsi transfer; motor learning; coactivation testing; electromyography; isometric strength; muscle recruitment
Massive and irreparable rotator cuff tears are a challenging situation for orthopedic surgeons. Current treatment strategies include rotator cuff repairs with augmentation, tendon transfer techniques, and reverse shoulder arthroplasty. Reverse shoulder arthroplasty is typically reserved for less active and elderly patients, whereas latissimus dorsi transfer has become an established surgical treatment option for massive and irreparable posterosuperior rotator cuff tears in younger patients without glenohumeral osteoarthritis. 3,7-9,11,14,17,21-23

Postoperative shoulder function and patient satisfaction after latissimus dorsi transfer have been reported to be variable, and the reasons for this remain only partially understood. 10,16,17,22,29 By transfer of the latissimus dorsi tendon from its native insertion to the greater tuberosity, biomechanical function changes from internal rotation and adduction to external rotation and abduction. Although some authors see the major effect of latissimus dorsi transfer in a soft tissue rebalancing of the glenohumeral joint (tenodesis effect), most studies reveal better clinical results and higher patient satisfaction if the transferred muscle shows electromyographic (EMG) activity in its new function. 2,11,12,16,17,29

Werner et al 29 selected latissimus dorsi transfer patients with the best and the worst postoperative outcomes as assessed by Constant scores. They found that the patients in the better outcomes group had superior psychomotor skills and strong innervation of the transferred latissimus muscle.

To our knowledge, no simple clinical tool has yet been established to evaluate the muscle’s ability to adapt to its new function. The purpose of this study was to investigate cointaneous activation (coactivation) of the latissimus dorsi in its new function, as an external rotator, and in its native function, as an extensor and adductor, for the purpose of creating a clinical tool to monitor motor learning in the postoperative setting. Furthermore, we evaluated the correlation of selective EMG activity of the transferred muscle and clinical outcome. We hypothesized that patients with inferior score outcomes would show an inadequate motor learning process and that coactivation (CoA) testing is a valuable tool to evaluate the status of postoperative motor learning after latissimus dorsi transfer.

Methods

Between 2003 and 2009, 29 consecutive patients (3 women and 26 men) underwent a latissimus dorsi tendon transfer at the Department of Orthopedic Sports Medicine, München. The indication for performing this procedure was a complete, irreparable posterosuperior rotator cuff lesion in younger patients with a primary complaint of a functional deficit rather than pain. Contraindications were advanced osteoarthritis, shoulder stiffness, and deltoid or subscapularis insufficiency. Preoperatively, all patients had a complete history, physical examination, and diagnostic imaging, including shoulder radiographs in 3 planes and magnetic resonance imaging.

Only patients with a follow-up of more than 24 months were included in the study. Exclusion criteria were a postoperative tear of the transferred tendon on ultrasound imaging, advanced osteoarthritis, shoulder stiffness, septic arthritis, and severe neurologic disorders. All patients were contacted by telephone and offered enrollment in the study.

Surgical technique

The latissimus dorsi tendon transfer was performed as described by Gerber et al. 9,11 An angulated dorsal incision was used for the latissimus dorsi approach. The muscle was sharply detached from its humeral insertion and mobilized by blunt dissection to provide sufficient excursion for transfer.

Through an anterolateral deltoid split approach, the torn rotator cuff was identified and mobilized, and the greater tuberosity insertion site was prepared for the tendon transfer. A space was then created between the rotator cuff and deltoid muscle, through which the latissimus dorsi tendon was passed and subsequently fixed to the supraspinatus and infraspinatus footprint at the greater tuberosity with titanium suture anchors (Arthrex, Naples, FL, USA) in a modified Mason-Allen suture technique. Anteriorly, the tendon was sutured to the superior edge of the subscapularis. Medially, the torn and retracted edges of the rotator cuff were sutured to the transferred tendon. If there was a partial or complete tear of the cranial subscapularis tendon, this was repaired with the same suture anchors.

Postoperatively, the arm was immobilized in a thorax abduction cast in 45° of abduction, 30° of flexion, and 0° of rotation for 6 weeks. Passive exercises were initiated in 45° of abduction and limited to 0° of internal rotation, with external rotation as tolerated. Abduction was allowed up to 90°. In week 4, active-assisted exercises were initiated, with gradual gain in range of motion after 6 weeks. Unlimited active range of motion was permitted from week 10 on.

Clinical outcome measures

Patients were evaluated by the American Shoulder and Elbow Surgeon (ASES) score and the University of California–Los Angeles (UCLA) shoulder rating scale. 1,27 Further clinical examination included a visual analog scale score for the average pain level (0 representing no pain and 10 representing maximal imaginable pain) and testing for external rotational lag sign. 24

All patients were asked to report their overall satisfaction with the surgical outcome (satisfied vs nonsatisfied).

Diagnostic imaging

All preoperative magnetic resonance imaging scans were assessed for integrity and atrophy of the rotator cuff by 2 experienced orthopedic surgeons. The integrity of the subscapularis tendon was classified according to Fox and Romeo. 8 The posterosuperior rotator cuff lesions (supraspinatus and infraspinatus) were graded by the classification system of Goutallier for muscle atrophy and by the Patte system for tendon retraction. 13,26 The teres minor tendon was graded as intact, partially torn, or completely torn and was also assessed according to the Goutallier system for muscle atrophy. 8
At follow-up, the integrity of the transferred tendon was confirmed with ultrasound examination before CoA and muscle strength testing. The criteria for an intact tendon transfer were sufficient tendinous footprint coverage at the greater tuberosity and an intact tendon structure up to the myotendinous junction. Patients with evidence of a re-rupture of the transferred tendon were excluded from further examination.

Coactivation and isometric strength testing

Biomechanically, after transfer to the greater tuberosity, the latissimus dorsi tendon acquires an external rotation function. Activation of the latissimus dorsi muscle will therefore result in external rotation of the shoulder joint.

To evaluate the patient’s ability to activate the muscle in this new function, maximal active external rotation (aER) was assessed with a hand-held goniometer. The patient was in a seated position with the elbow at the side (Fig. 1, A). The latissimus dorsi was then simultaneously activated in its native function as an extensor and adductor by use of a cable system with an 8-kg counterweight and sling, which was placed just above the elbow joint (Fig. 1, B). This CoA causes simultaneous stimulation of the new and the former myoelectrical pathways, leading to latissimus dorsi muscle contraction and aER.

Testing was performed bilaterally with and without CoA of the latissimus dorsi muscle. All measurements were repeated twice, with a short break in between. The testing setup was based on a previously described procedure designed to facilitate motor learning in the postoperative rehabilitation process after latissimus dorsi tendon transfer.16,28

Bilateral isometric strength testing of external rotation and abduction was performed with an Isobex isometric dynamometer (Cursor SA, Bern, Switzerland). The patient positioning for external rotation strength testing was identical to aER measurement, with the elbow and forearm in line, pointing straight ahead throughout the entire measurement procedure (Fig. 2, A). Strength testing of abduction was also assessed with the patient in a seated position and the arm in 90° of elevation in the scapular plane and the forearm in pronation, as previously defined for Constant score strength measurement (Fig. 2, B).4,30 In both positions, the Isobex cuff was attached to the patient’s wrist.

All patients were comprehensively introduced to each testing procedure and had time to familiarize themselves with the setup. In case of deviation from the testing position, the measurement was terminated and repeated. All measurements were performed in front of a mirror as a visual aid for the patients.

Electromyography

EMG activity of the latissimus dorsi muscle and the spinal part of the deltoid muscle was measured bilaterally throughout the CoA and strength testing procedure. Measurements were performed with a wireless EMG system (myon RFTD; Myon AG, Schwarzenberg, Switzerland) with a floating ground and bipolar surface electrodes (AMBU BlueSensor P, Ambu GmbH, Bad Nauheim, Germany). Subject preparation and placement of electrodes were conducted following the guidelines of the SENIAM group.15

The latissimus dorsi muscle electrodes were positioned distally and laterally to the inferior angle of the scapula above the bulkiest muscle portion, as described in the literature.25,29 The electrodes for deltoid activity recording were placed just below the posterolateral edge of the acromion, above the posterior deltoid. Interelectrode distance was 2 cm, and EMG signals were amplified no farther than 10 cm from the recording site. Data were collected at a sampling rate of 1000 Hz and bandpass filtered (Butterworth, 10-500 Hz). EMG data were further processed with root-mean-square smoothing (500 ms) and normalized to maximum voluntary activation (MVA). For maximum activity in aER, means of 3 trials were calculated.

Furthermore, ratios of latissimus dorsi activity with CoA to activity without CoA were determined. Small EMG activity ratios represent relatively low latissimus dorsi activation in CoA tasks (native function) and relatively high EMG activity during aER without CoA (new function), indicating superior motor learning.

The EMG activity of the deltoid muscle indicated the start of external rotation and allowed a consistent and reliable analysis of the EMG data.

Figure 1  Maximum active external rotation measurements with the patient in a seated position and the elbow at the side. (A) Without coactivation. (B) With coactivation testing by use of a cable system at 8-kg counterweight and a sling.
Classifying by clinical outcome

Shoulder score test results were used to separate patients into two groups: good/excellent and fair/poor outcomes. For statistical analysis, each shoulder rating score was evaluated separately. ASES score results of shoulder function were considered excellent (86-100 points), good (71-85 points), fair (56-70 points), and poor (<55 points).\(^2\) For the UCLA score, outcomes were rated excellent (34-35 points), good (28-33 points), fair (21-27 points), and poor (<20 points).\(^1\)

Statistics

Statistical analyses were performed with SPSS software version 20 for Mac (SPSS Inc, Chicago, IL, USA). The level of significance was set at \(P < .05\).

The aER with and without CoA, isometric strength in external rotation and abduction, and EMG activity of the transferred latissimus dorsi muscle were compared between the two outcome groups. Gain in aER through CoA and ratios for EMG activity (latissimus dorsi activity with CoA to activity without CoA) were calculated.

Nonparametric tests (Mann-Whitney \(U\) test for independent samples and Wilcoxon signed rank test for dependent samples) were used for group comparison.

Results

We evaluated 20 (2 women, 18 men) of 29 patients clinically and sonographically at an average follow-up of 57.8 ± 25.2 months. Four patients refused to participate in this follow-up examination, 2 patients could not be found, and 1 patient was deceased. A female patient had a severe cervical spine injury and could not be adequately assessed. Another patient had a reverse shoulder prosthesis implanted at the time of the latissimus transfer and was therefore excluded from the study. There were no neurovascular complications or postoperative infections within our patient cohort.

Ultrasound imaging revealed questionable integrity or rupture of the transferred tendon in 4 patients (20%). One patient reported a gradual loss of shoulder function over time; another patient had an abrupt loss of function after a severe motor vehicle accident. Both individuals were initially satisfied with the surgical result. Two patients had early failure and never reached a functional level better than their preoperative status.

After exclusion of patients with rupture of the transferred tendon, 16 patients (2 women, 14 men) completed the entire study protocol. The average follow-up was 54.4 ± 24.3 months. Age at surgery was 57.3 ± 9.2 years.

Clinical outcome

The overall ASES score in this patient population was 77.4 ± 17.1 points. The UCLA score was 29.0 ± 3.7 points. The average visual analog scale score for pain was 1.7 ± 1.7 of 10. Satisfaction with the outcome was reported by 14 patients, who would undergo latissimus dorsi transfer again; 2 patients were unsatisfied and would not have this procedure again. Of 16 patients, 7 showed a persistent positive external rotational lag sign in 0° of abduction at follow-up.

Imaging

Preoperative magnetic resonance imaging revealed highly retracted and degenerated posterosuperior rotator cuff lesions (Table I). The teres minor tendon, however, was intact or had only a partial tear. In most patients, the subscapularis tendon had a partial tear; 2 patients presented with a complete tear superiorly (Fox and Romeo\(^8\) grade 2). In 3 patients, the grade of fatty rotator cuff degeneration could not be assessed because of insufficient medial imaging of the muscles.

No differences in tendon integrity or degree of atrophy of the rotator cuff could be observed between groups on preoperatives magnetic resonance imaging scans.
Table I  Preoperative magnetic resonance imaging results

<table>
<thead>
<tr>
<th></th>
<th>Median (range)</th>
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<tbody>
<tr>
<td><strong>Supraspinatus</strong></td>
<td></td>
</tr>
<tr>
<td>Tendon retraction/Patte (n = 16)</td>
<td>3 (2-3)</td>
</tr>
<tr>
<td>Fatty infiltration/Goutallier (n = 13)</td>
<td>3 (2-4)</td>
</tr>
<tr>
<td><strong>Infraspinatus</strong></td>
<td></td>
</tr>
<tr>
<td>Tendon retraction/Patte (n = 16)</td>
<td>2 (1-3)</td>
</tr>
<tr>
<td>Fatty infiltration/Goutallier (n = 16)</td>
<td>4 (2-4)</td>
</tr>
<tr>
<td><strong>Teres minor</strong></td>
<td></td>
</tr>
<tr>
<td>Integrity (n = 16)</td>
<td>1 (1-2)</td>
</tr>
<tr>
<td>Fatty infiltration/Goutallier (n = 13)</td>
<td>1 (0-4)</td>
</tr>
<tr>
<td><strong>Subscapularis</strong></td>
<td></td>
</tr>
<tr>
<td>Integrity/Fox and Romeo (n = 16)</td>
<td>1 (0-2)</td>
</tr>
</tbody>
</table>

Tendon retraction was graded according to Patte, fatty infiltration according to Goutallier. Teres minor integrity was classified as follows: 1, intact; 2, partial lesion; and 3, complete lesion. For subscapularis lesions, the Fox and Romeo classification was used. Fatty infiltration could not be assessed in 3 cases because of insufficient imaging of the medial muscle belly.

**Range of motion and strength testing**

In the patient cohort as a whole, muscle CoA did not have an impact on aER of the surgically treated extremity (P = .396). In the contralateral shoulder, however, a significant decrease in aER was observed when the latissimus dorsi muscle was simultaneously activated (P = .014). There were no significant differences in the gain or loss of aER through CoA when a bilateral comparison was performed (P = .071) (Table II). Isometric strength testing of the side operated on revealed significantly lower strength values compared with the contralateral extremity for both external rotation and abduction (P = .017; P = .009).

On subdivision of the patient population by clinical outcome scores into patients with good or excellent outcomes and patients with fair or poor outcomes, the mean aER of the superior outcome group was higher than that of the poor outcome group for both the ASES and UCLA scores. However, only the difference in the UCLA scores revealed statistical significance (P = .042).

With the application of muscle CoA, the inferior outcome group could gain additional aER, whereas the superior outcome group lost aER. These results reached statistical significance only in the UCLA score subdivision (P = .031). The data as well as the distribution of patients within each subgroup according to the clinical score results are shown in Table III.

**Electromyography**

EMG data throughout aER showed comparable bilateral activity of the latissimus dorsi (P = .266). CoA testing did increase latissimus dorsi activity significantly from 49.9 ± 12.4 to 88.2 ± 7.8 MVA (P < .001) on the surgical side and from 42.7 ± 17.1 to 81.5 ± 19.3 MVA (P < .001) on the nonsurgical side, with no statistically significant difference between the affected and unaffected shoulders (Table II).

Analysis of isometric strength testing of external rotation and abduction revealed a significantly higher EMG activity in the operated shoulder compared with the contralateral side for both movements (P = .008; P = .006) (Table II).

On subdivision of the patient population by clinical outcome scores, higher mean latissimus dorsi activity was observed in the group with better clinical outcome scores. Furthermore, patients with superior outcomes demonstrated a lower EMG activity ratio, which indicates the relationship of the muscle’s activity in its new and in its native function. However, statistical significance was reached only for ASES score subdivision (P = .027) (Table III).

**Discussion**

The primary aim of this study was to assess CoA testing as a clinical tool to monitor motor learning after latissimus dorsi tendon transfer. When we categorized our patient population by shoulder score test results, muscle CoA testing showed a distinct pattern of aER and EMG activity. Patients with fair or poor outcome showed a tendency to gain additional aER when simultaneously activating the muscle in its native function, indicating an insufficient motor learning process. Patients with good and excellent clinical results did not depend on CoA to achieve maximal aER and may have learned to use the latissimus partially as an external rotator.

Table II  Maximum active external rotation in 0° of abduction, latissimus dorsi electromyographic activity, and isometric strength for the patient population as a whole

<table>
<thead>
<tr>
<th></th>
<th>LD transfer</th>
<th>Contralateral</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without CoA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aER</td>
<td>19.8 ± 16.8</td>
<td>41.8 ± 14.9</td>
<td>.005</td>
</tr>
<tr>
<td>LD EMG activity</td>
<td>49.9 ± 12.4</td>
<td>42.7 ± 17.7</td>
<td>.266</td>
</tr>
<tr>
<td><strong>With CoA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aER</td>
<td>20.4 ± 18.0</td>
<td>38.2 ± 13.7</td>
<td>.011</td>
</tr>
<tr>
<td>LD EMG activity</td>
<td>88.2 ± 7.8</td>
<td>81.5 ± 19.3</td>
<td>.278</td>
</tr>
<tr>
<td>aER gain through CoA</td>
<td>0.6 ± 6.8</td>
<td>−3.6 ± 5.0</td>
<td>.071</td>
</tr>
<tr>
<td>LD EMG activity ratio</td>
<td>1.9 ± 0.5</td>
<td>2.3 ± 1.3</td>
<td>.438</td>
</tr>
<tr>
<td><strong>CoA/no CoA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isometric external rotation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength (kg)</td>
<td>4.7 ± 2.5</td>
<td>6.6 ± 2.4</td>
<td>.017</td>
</tr>
<tr>
<td>LD EMG activity</td>
<td>50.8 ± 25.1</td>
<td>31.6 ± 23.7</td>
<td>.008</td>
</tr>
<tr>
<td>Isometric abduction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength (kg)</td>
<td>2.8 ± 1.9</td>
<td>5.7 ± 2.9</td>
<td>.009</td>
</tr>
<tr>
<td>LD EMG activity</td>
<td>51.5 ± 24.4</td>
<td>30.2 ± 15.0</td>
<td>.006</td>
</tr>
</tbody>
</table>

aER, active range of external rotation; CoA, coactivation; EMG, electromyography; LD, latissimus dorsi; SD, standard deviation. Bold values indicate statistical significance.
EMG data support these clinical observations in that higher activity ratios were seen in the inferior outcome group, indicating a relatively high activity of the latissimus dorsi in its former function and a low activity in its actual function as external rotator. However, clinical and EMG data only partially reach statistical significance, and data should be interpreted accordingly.

The clinical outcome and pain scores in our patient population are comparable to those in the current literature. Also, the rate of tendon transfer rupture (20%) is similar to that of previously published diagnostic imaging studies. Therefore, our study population is likely representative of the patient population after latissimus dorsi transfer.

In the patient cohort as a whole, CoA testing had no impact on aER in the affected shoulder while significantly reducing aER on the nonsurgical side. This observation can be explained by the internal rotational momentum of the native latissimus dorsi muscle, which acts as an antagonist to aER. Contracting the latissimus dorsi on the nonsurgical side during CoA testing may therefore hinder aER. Furthermore, the slight loss of aER within this group through CoA may be attributed to an interfering CoA setup with a sling and counterweight.

Interestingly, there was high latissimus dorsi muscle activity in aER in the unaffected shoulder with no significant difference between surgical and nonsurgical sides.

These results support the findings of Werner et al., who also reported a high bilateral EMG activity of the latissimus dorsi in flexion, abduction, and external rotation testing. During execution of external rotation, Werner et al. found even a comparable latissimus dorsi EMG activity in the shoulder tested and in the shoulder at rest. This was evident regardless of whether the surgical or the nonsurgical side performed external rotation tasks. They attributed this observation to a trunk-stabilizing function of the latissimus dorsi during testing. However, after their patients were divided by Constant score outcome, it was noted that the superior outcome group had significantly higher EMG values in the shoulder that was operated on compared with the contralateral shoulder.

In our patient population, a stronger EMG signal was also associated with the better ASES score subdivision. Unfortunately, Werner et al. presented only results, which makes it impossible to compare our raw EMG data directly with theirs.

Irlenbusch et al. evaluated the impact of EMG activity of the latissimus dorsi on Constant score outcome in 23 patients, 9 months after surgery, and found a clear, positive correlation. However, they reported only data normalized to the contralateral side for activity of latissimus dorsi during flexion, abduction, and elevation. Thus, we do not know about absolute latissimus activity on the contralateral side.

Irlenbusch et al. and Werner et al. normalized their EMG data to the contralateral side, whereas we normalized our data to MVA of each muscle. It is well known that surface EMG is highly influenced by a number of factors, such as subcutaneous tissue and electrode configuration and location. In our opinion, EMG data normalization to the contralateral shoulder after muscle transfer may be affected not only by divergent electrode placement but also by the nonanatomic surgical procedure itself.

Despite normalization to MVA and a strict measuring protocol, our EMG data showed a high degree of variability. This is particularly surprising as the latissimus dorsi muscle is easily accessible by surface EMG, and the summation potential of the muscle on surface EMG is more representative than with needle EMG, in which only certain portions of the muscle are recorded.

However, contributions of synergistic muscles such as the teres minor and major may have affected our data. This impact is difficult to assess retrospectively, but it is reported to be up to 17% of recorded signals in other muscle groups. Again, we are unable to compare our results because of unavailable raw data. However, other authors have previously reported on variable and inconclusive EMG results after latissimus dorsi muscle transfer.
In summary, our data only partially support the hypothesis that clinical outcome is dependent on the ability to activate the latissimus dorsi in external rotation and that CoA testing is an appropriate tool to follow up motor learning. The strong relationship between clinical outcome and EMG activity, as presented by Irlenbusch et al., could not be confirmed.

In our clinical experience, CoA testing works well in some patients, whereas in others, no significant impact was seen (Fig. 3). So far, we do not know which patients respond well to CoA testing.

There are a number of patient factors and limitations of our study. CoA testing with a permanent active extension movement by use of a cable system at 8-kg counterweight was chosen to create a reproducible and standardized procedure. However, it does not take into account the patient’s individual physical and coordinative abilities. This may have an impact on aER, especially in weaker and elderly patients. Future application of CoA testing for clinical and scientific investigations should take individual motor capacities more into account.

Irlenbusch et al. recorded the EMG activity of the latissimus dorsi transfer at 6 weeks and at 6, 12, and 19 months postoperatively and reported a steady increase of latissimus dorsi activity up to 1 year postoperatively with a decrease at final follow-up of 19 months. This may be explained by the intensive physical therapy and rehabilitation that takes place within the first year after surgery. With a mean follow-up of 54.4 ± 24.3 months, our patients may have lost the initial ability to actively contract the muscle. Subsequent muscle atrophy and secondary anterior shoulder capsule tightness may affect aER and EMG data.

Costouros et al. found that fatty infiltration of the teres minor muscle influences aER after latissimus dorsi transfer. Teres minor insufficiency may also affect CoA testing through its impact on external rotation of the shoulder. Voluntary activation of the latissimus dorsi and CoA testing may be relevant only in the case of total external rotator deficiency. However, in our study, only the preoperative status of the teres minor muscle was assessed and showed no increased fatty infiltration.

Interestingly, our isometric strength testing data for external rotation and abduction revealed greater latissimus dorsi EMG activity but inferior strength in the shoulder that was operated on compared with the contralateral one. Furthermore, the amount of EMG activity of the latissimus dorsi in external rotation did not achieve the same level of activity as with simultaneous CoA in any patient, suggesting that recruitment of the entire latissimus dorsi in aER does not occur. This raises the possibility that the clinical outcome may be only partially affected by the ability to actively contract the latissimus dorsi. We believe that recentering of the glenohumeral joint and the teres minor plays an essential role in latissimus dorsi tendon transfer and that both a tenodesis effect and voluntary muscle activation are associated with a good result.

Another limitation is the limited number of cases in our study, which may have led to a type II error. Although latissimus dorsi transfer is an established treatment option in irreparable posterosuperior rotator cuff tear, we consider it...
Finally, there is evidence in the literature that psychomotor findings are correlated to postoperative outcome after latissimus dorsi tendon transfer. However, psychomotor capabilities were not assessed in this study and may have influenced our test results.

**Conclusion**

CoA testing is a valuable tool to evaluate the status of postoperative motor learning after latissimus dorsi transfer. Patients with a fair or poor outcome showed a tendency to gain additional external rotation when simultaneously activating the muscle in its native function, indicating an insufficient motor learning process. However, further studies with larger patient numbers and a longitudinal study setup are necessary.

**Acknowledgment**

We thank Olga Solovyova, MD (Hospital for Joint Disease, New York, NY, USA) for improving our English in the manuscript.

**Disclaimer**

The authors, their immediate families, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

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