



SHOULDER

Increased co-contraction of arm adductors is associated with a favorable course in subacromial pain syndrome



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Background: Enhancement of arm adductor activity during abduction (ie, adductor co-contraction), may be effective in the treatment of subacromial pain syndrome (SAPS). We assessed whether an increase of adductor co-contraction is associated with a favorable course of SAPS.

Methods: At baseline and after nearly 4 years of follow-up, electromyography of the latissimus dorsi (LD), teres major (TM), pectoralis major, and deltoid muscle was obtained during isometric abduction and adduction tasks in 26 patients with SAPS. Changes in co-contraction were assessed with change in the activation ratio (Δ AR). The AR ranges between -1 and 1 , where lower values indicate more co-contraction. Clinical course was determined from an anchor question (reduced, persistent, or increased complaints), the visual analog scale for pain (VAS), and the Western Ontario Rotator Cuff score (WORC).

Results: In patients indicating persistent complaints (31%), the VAS and WORC remained stable. In patients who indicated reduced complaints (69%), the VAS reduced (z score, -3.4 ; $P = .001$) and WORC increased (z score, 3.6 ; $P < .001$). Unchanged ARs associated with complaints persistence, whereas decreased AR of the LD (Δ AR_{LD}, -0.21 ; 95% confidence interval [CI], -0.36 to -0.06) and TM (Δ AR_{TM}, -0.17 ; 95% CI, -0.34 to -0.00) coincided with reduced complaints. There was a significant between-group difference in Δ AR_{LD} (-0.35 ; 95% CI, -0.60 to 0.10) and Δ AR_{TM} (-0.36 ; 95% CI, -0.66 to -0.05).

Conclusions: Increased co-contraction of the LD and TM is associated with a favorable course of SAPS. This may be explained by widening of the subacromial space accomplished by adductor co-contraction.

Level of evidence: Level I; Prospective Design; Prognostic Study

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The Leiden University Medical Center Medical Ethical Committee approved this study (P09.227).

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During abduction of the arm, muscles that generate the moment for shoulder movement simultaneously generate a resultant force through the glenoid that stabilizes the glenohumeral joint.³⁰ Studies have suggested that this active stabilization is compromised in the subacromial pain syndrome (SAPS), leading to painful upward migration of the humerus.^{7,14,23,24,29} Model simulation and radiographic analyses show that humeral migration may be counteracted with activation of arm adductors during abduction (ie, adductor co-contraction).^{15,16,26} Therefore, increasing co-contraction of arm adductors, such as the latissimus dorsi (LD), teres major (TM), and pectoralis major (PM), may be beneficial for patients with SAPS.

Few studies have investigated arm adductor co-contraction in SAPS, and there is currently no evidence for alterations in activation patterns.^{3,10,25} Moreover, longitudinal electromyography (EMG) assessments to support the theory that increasing adductor co-contraction is beneficial in SAPS are yet lacking. In this study, we tested the hypothesis that increased arm adductor co-contraction would be associated with a favorable course of SAPS. In a prospective cohort with EMG assessment, changes in muscle activation of the LD, TM, PM, and deltoid muscle (DM) were related to changes in complaints after nearly 4 years of follow-up.

Materials and methods

Between April 2010 and December 2012, 32 patients were recruited at the Leiden University Medical Center, Haaglanden Medical Center, and Alrijne Hospital, under a previously registered and published study protocol (Netherlands Trial Register No. NTR2283).¹¹ Patients with SAPS were selected using strict criteria on clinical examination and magnetic resonance arthrography.¹¹ Inclusion criteria were a positive Neer impingement test, a positive Hawkins test, and 1 or more additional criteria, including painful arc, shoulder complaints for longer than 3 months, or diffuse pain during palpation of the greater tuberosity.¹¹ Exclusion criteria included but were not limited to the presence of previous fracture or dislocation of the shoulder, frozen shoulder, comorbidities of the affected shoulder (eg, tumor, instability), full-thickness rotator cuff tears, or calcific tendinitis.¹¹ All patients gave written informed consent. After a period of usual care (eg, physical therapy, subacromial injections), the 32 included patients were contacted for a follow-up visit between June 2014 and September 2015.

Measurement set-up

For EMG measurements, participants were standing with the affected arm in external rotation at the side, facing a screen where the recorded force exertion was visualized (Fig. 1). This testing

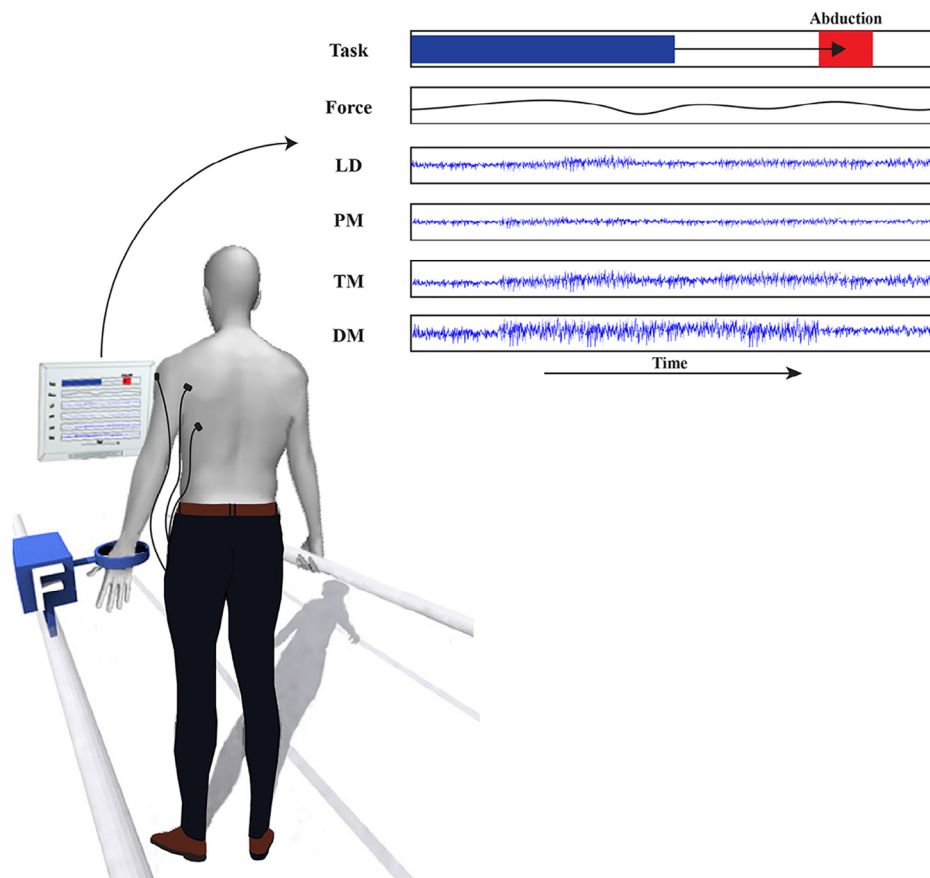


Figure 1 Electromyography measurements during isometric force tasks. *LD*, latissimus dorsi; *PM*, pectoralis major; *TM*, teres major; *DM*, deltoid muscle.

position with the arm at the side was chosen so that all patients with SAPS could be evaluated, including those who could not abduct (fully) because of pain. We were also interested in typifying muscle activation strategies that patients use to generate an abduction moment rather than in assessing the influence of pain on muscle activation patterns.

In this position of relative rest and during abduction and adduction tasks against a 1-dimensional force transducer at the wrist, EMG of 3 shoulder adductors (LD, TM, and PM, clavicular part) and the main shoulder abductor (DM, medial part) were recorded with a bipolar surface EMG system (Bagnoli-16; Delsys, Boston, MA, USA), with an interelectrode distance of 10 mm and bandwidth of 20 to 450 Hz, as previously described in detail.¹¹ EMG and force signals were analog-digitally (AD) converted and recorded simultaneously at a sample rate of 2500 Hz. For offset removal, the mean was subtracted, and the EMG signals were rectified and enveloped (moving average) using custom-made MATLAB software (MathWorks Inc., Natick, MA, USA). Corrupt EMG data or EMG signals that did not reach a 2-fold signal-to-noise ratio were excluded.

During the measurements, the maximal voluntary force (MVF) was first determined as the lowest absolute value of the MVF during isometric abduction and adduction. Second, participants performed an abduction and adduction force task at $60\% \pm 3.75\%$ MVF. Muscle co-contraction was quantified using the activation ratio (AR), which is a reliable method to interpret EMG activity in a standardized manner and based on the muscles' principal action.^{8,12} According to the principle action, muscle activation is expressed as agonistic "in-phase" activation (EMG^{IP}) and antagonistic "out-of-phase" activation (EMG^{OP}).⁸ For example, activation of the DM during the isometric abduction force task is called EMG^{IP} and activation during the adduction force task is called EMG^{OP} . These values were used to calculate ARs for LD, TM, PM, or DM (AR_{muscle}) using Eq. 1:

$$AR_{muscle} = \frac{EMG^{IP} - EMG^{OP}}{EMG^{IP} + EMG^{OP}} \quad -1 \leq AR_{muscle} \leq 1$$

Outcome measures

Co-contraction

Changes in co-contraction were monitored using the AR (-1 to 1), where lower values indicate relatively more antagonistic activity (ie, co-contraction).¹² We also recorded the unstandardized group averages of the agonistic EMG^{IP} and antagonistic EMG^{OP} activity. Lastly, we used the magnitude of the force task to assess whether this mediated changes in AR.

Clinical course

- Anchor question for complaints persistence: The primary end point was an anchor question that assessed whether complaints had changed compared with the first visit, with 3 possible answers: persistent complaints, reduced complaints, or more complaints. For the analyses of the association between ARs and the clinical course, patients were subgrouped according to their answers on the anchor question.
- Visual analog scale for pain during motion (VAS): Pain during arm movement was scored at baseline and follow-up using a 100-mm VAS scale, where 0 indicated no pain and 100 indicated maximal pain. We assessed whether changes in the VAS over time corresponded with answers on the anchor question

and whether the change in the VAS score exceeded the minimal clinically important difference (MCID) of 14 mm determined in patients with rotator cuff disease.²⁸

- Western Ontario Rotator Cuff score (WORC): The WORC is a clinical score focused at rotator cuff diseases assessing 5 domains in 21 items: physical symptoms, sports and recreation, work, lifestyle, and emotions.⁹ The score ranges from 0 (worst possible) to 100 (best possible). We assessed whether changes in WORC over time corresponded with answers on the anchor question and whether the change in WORC score exceeded the MCID of 11.7 points determined in patients with rotator cuff disease.^{9,20}

Statistical analysis

Categoric data are described with numbers and percentages. Continuous data are described with means, standard deviation (SD), and 95% confidence intervals (CIs) in case of normally distributed data or with medians and quartiles in case of nonparametric data (histograms).

We used linear mixed models (LMM) to assess changes and intergroup differences in ARs over time (ie, ΔAR_{muscle}). Dependent variables were the ARs of the LD, PM, TM, or DM. In a fixed effects model, the clinical course was included as a factor and the measurement moment as a covariate. An interaction term between measurement moment and clinical course was included to assess whether patients with a different clinical course (anchor question) differed in ΔAR_{muscle} . In addition, to rule out that the magnitude of force task during EMG tasks mediated possible changes in ARs, we conducted a simple LMM with fixed effect force task and dependent variable ARs.⁴ Results from the LMM are presented as estimated group means, estimated group differences, 95% CIs, and *P* values. Depending on the distribution of data, changes in VAS and WORC scores over time were assessed by means of the paired samples *t* test or the Wilcoxon signed rank test. SPSS 20 software (IBM Corp., Armonk, NY, USA) was used for statistical analysis. A 2-sided *P* value of ≤ 0.05 was considered statistically significant.

Results

Patient characteristics

At follow-up, 3 patients declined participation, 2 could not be contacted, and 1 had died, leaving a study cohort of 26 patients (76%) with baseline and follow-up data. Baseline characteristics of the included patients are described in [Table I](#). During the follow-up period of 3.8 (SD, 0.48) years, patients reported having received only exercise therapy ($n = 6$ [23%]), only subacromial infiltrations ($n = 3$ [12%]) or both ($n = 13$ [50%]), and a wait-and-see policy ($n = 4$ [15%]).

Clinical course of complaints

Compared with the first visit, none of the patients had increased complaints after the follow-up period, 8 patients (31%) had persistent complaints, and 18 (69%) had reduced complaints. Of the patients with persistent complaints, 1 (13%) reported to have only received subacromial infiltrations, and

Table I Baseline characteristics of patients with the subacromial pain syndrome

Demographics	Total group (n = 32)	
	With follow-up	Loss to follow-up
	(n = 26)	(n = 6)
Age, mean (SD) yrs	50 (6.4)	53 (4.8)
Female, No. (%)	16 (62)	3 (50)
Right-side dominance, No. (%)	23 (89)	5 (83)
Dominant side affected, No. (%)	16 (62)	4 (67)
Body mass index, mean (SD) kg/m ²	27 (4.5)	25 (1.5)
Duration of complaints, median (quartiles), mo	18 (12-29)	12 (10-30)

SD, standard deviation.

6 (75%) reported to have received exercise therapy and subacromial infiltrations. In patients with persistent complaints, the median VAS was 47 (quartiles, 19-63) at baseline and 54 (quartiles, 21-77) at follow-up (z score, -0.35 ; $P = .726$). The WORC showed no significant changes in these patients, with median scores of 57 (quartiles, 51-68) at baseline and 44 (quartiles, 34-67) at follow-up (z score, -0.98 ; $P = .327$). Conversely, in patients with reduced complaints, the VAS reduced from 32 (quartiles, 17-62) at baseline to 5.9 (quartiles, 2.0-34) at follow-up (z score, -3.4 ; $P = .001$), exceeding the MCID.²⁸ The WORC also showed clinical improvement, exceeding the MCID, with a median score of 60 (quartiles, 43-74) at baseline and 92 (quartiles, 75-95) at follow-up (z score, -3.6 ; $P < .001$).²⁰

Muscle activation in association with clinical course

At baseline, there were no differences in ARs between patients who indicated persistent or reduced complaints at follow-up (Fig. 2, Table II). Over time, there were no significant changes in the AR of the LD in patients with persistent complaints (ΔAR_{LD} , 0.14; 95% CI, -0.06 to 0.34). However, in patients with reduced complaints, the AR of the LD significantly decreased (ΔAR_{LD} , -0.21 ; 95% CI, -0.36 to -0.06), indicating significantly increased co-contraction. The groups significantly differed in ΔAR_{LD} (group difference in ΔAR_{LD} , -0.35 ; 95% CI, -0.60 to -0.10 , $P = .009$). Also regarding the TM, patients with persistent complaints had no significant changes in the AR (ΔAR_{TM} , 0.19; 95% CI, -0.07 to 0.44), whereas patients with reduced complaints had a significant decrease in AR of the TM (ΔAR_{TM} , -0.17 ; 95% CI, -0.34 to -0.00), indicating increased co-contraction. This resulted in a group difference of -0.36 (95% CI, -0.66 to -0.05 ; $P = .023$). There were no significant group differences in the ΔAR_{PM} (-0.08 ; 95% CI, -0.31 to 0.15) or ΔAR_{DM} (0.16; 95% CI, -0.01 to 0.32). Lastly, no association was found between the magnitude of force task during measurements and the AR

of the LD (-0.07 ; 95% CI, -0.24 to 0.11; $P = .438$), TM (-0.04 ; 95% CI, -0.28 to 0.20; $P = .724$), PM (0.06; 95% CI, -0.09 to 0.21, $P = .417$), or DM (-0.01 , 95% CI, -0.11 to 0.10; $P = .886$).

Unstandardized agonistic (EMG^{IP}) and antagonistic (EMG^{OP}) activity

In accordance with the presented ARs, the coinciding unstandardized EMG^{IP} and EMG^{OP} signals revealed increased antagonistic EMG^{OP} of the LD and TM in the group with reduced complaints at follow-up and decreased antagonistic EMG^{OP} of the LD and TM in the group with persistent complaints at follow-up (Table III).

Discussion

In this cohort nearing 4 years of follow-up, we found that decreased ARs of the LD and TM were associated with patient-reported reduced complaints, significantly decreased pain (VAS), and significantly increased quality of life (WORC).²⁸ These improvements exceeded threshold values for a MCID, thus indicating a clinically relevant improvement.^{20,28} A favorable course of SAPS was associated with increased co-contraction of the LD and TM. Conversely, unchanged activation patterns of these adductors were associated with persistent complaints.

Activation patterns of scapular muscles (eg, upper trapezius) and glenohumeral muscles (eg, the infraspinatus) have been commonly assessed in the context of SAPS.¹⁹ In contrast, only a few studies have reported on activity of arm adductors in SAPS, representing a gap in knowledge.^{3,10,25} No differences in adductor activity between patients with SAPS and controls were found in 2 cross-sectional studies, except for a higher LD activation between 45° and 60° of concentric abduction.^{3,10} In another cross-sectional comparison of the affected and unaffected shoulder in SAPS, unaltered activation patterns were found of the LD and PM, among others.²⁵ Our study is the first to longitudinally assess adductor activation patterns in association with complaints in SAPS.

The observed association between increased adductor co-contraction and a favorable clinical course may suggest different underlying mechanisms. First, adductor co-contraction may be an adaptation to pain. In the presence of pain, agonistic activity may be reduced and antagonistic activity increased in an attempt to prevent (further) tissue damage.²¹ This theory is supported by several studies that observed acute altered muscle activation patterns, including reduced agonistic deltoid activity after inducing subacromial pain.^{2,6,13} In our study, EMG was assessed with the arm at the side where patients did not experience complaints; therefore, an acute adaptation to pain is not likely. Furthermore, patients with SAPS had more pain at baseline than at follow-up (VAS scores), and complaints at baseline had already lasted for a median of 17 months. Given this state of symptoms and that

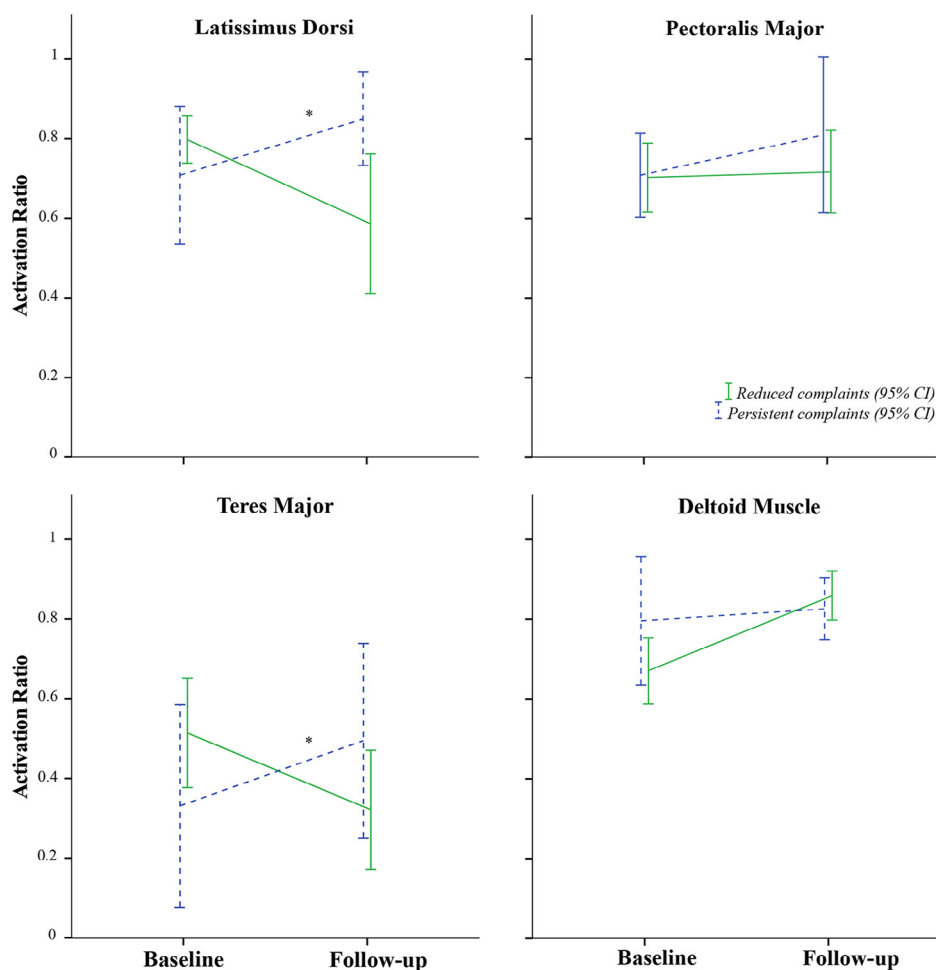


Figure 2 Change in activation ratios over time stratified for shoulder complaints at follow-up. The whiskers represent the 95% confidence intervals (CI). Lower activation ratios indicate relatively more co-contraction. *Significant difference ($\alpha = 0.05$) in activation ratio change between patients with persistent or reduced complaints at follow-up, based on linear mixed model analysis.

patients had less adductor co-contraction at baseline than at follow-up, the observed increased in adductor co-contraction was unlikely to be an adaptation to pain.

Alternatively, the association between increased adductor co-contraction and a favorable course of SAPS may indicate preceding insufficient adductor co-contraction. In other joints than the shoulder, increased co-contraction has been associated with normal aging.^{5,17,27} This finding is generally explained as a means to enhance joint stability under the influence of degeneration (eg, declining proprioception).^{5,17,27} Patients with SAPS possibly develop complaints because they adapt insufficiently to such age-related changes in the shoulder. The consequences may be even greater considering previous studies that showed an exaggerated loss of proprioception in SAPS.^{1,18,22}

No association was found between co-contraction of the PM and the clinical course of SAPS. Due to the more medially directed force vector of the PM, it may be that the PM is less effective in counteracting cranially directed forces when the arm is held at the side.²⁶ In higher regions of abduction, partially also due to presence of pain, co-contraction of the

PM may arguably be more effective. Skolimowski et al²⁵ tested activation of the PM during abduction (whole trajectory) and accordingly suggested development of compensatory activation during this movement.

Our study had some limitations. First, the comparison of ARs between patients with persistent or reduced complaints at follow-up was performed on relatively low numbers of patients. Despite the small sample size, we observed a convincing association between (increased) adductor co-contraction and the reduction of complaints. In the context of these findings and the current tendency toward personalized medicine, we believe that positive results in small study populations are of specific interest. A potential drawback is that findings may not be generalizable due to selection bias. We applied and described strict eligibility criteria to enhance the interpretation and reproduction of our findings.

Second, 39 ARs (17%) were missing because EMG data did not reach the 2-fold signal-to-noise ratio (12%) or was corrupt (5%; eg, problem with the amplifier).

Third, patients were treated according to current clinical practice, and we did not control for this. The type of treatment

Table II Activation ratios associated with complaints at follow-up using linear mixed model analysis

Activation ratio	Persistent complaints		Reduced complaints		Group difference		
	Mean	95% CI	Mean	95% CI	Mean	95% CI	P value
LD							
Baseline	0.71	0.60-0.82	0.80	0.73-0.87	0.09	-0.04 to 0.22	.165
Follow-up	0.85	0.66-1.0	0.59	0.45-0.73	-0.26	-0.50 to -0.03	.031
Δ AR	0.14	-0.06 to 0.34	-0.21	-0.36 to -0.06	-0.35	-0.60 to -0.10	.009
PM							
Baseline	0.71	0.59-0.82	0.70	0.62-0.78	-0.00	-0.14 to 0.13	.944
Follow-up	0.80	0.64-0.97	0.72	0.62-0.81	-0.09	-0.28 to 0.10	.350
Δ AR	0.09	-0.10 to 0.29	0.01	-0.11 to 0.13	-0.08	-0.31 to 0.15	.459
TM							
Baseline	0.32	0.11-0.53	0.52	0.38-0.65	0.20	-0.05 to 0.44	.118
Follow-up	0.51	0.30-0.71	0.34	0.20-0.48	-0.16	-0.41 to 0.09	.190
Δ AR	0.19	-0.07 to 0.44	-0.17	-0.34 to -0.00	-0.36	-0.66 to -0.05	.023
DM							
Baseline	0.80	0.67-0.92	0.67	0.59-0.76	-0.13	-0.28 to 0.03	.100
Follow-up	0.83	0.75-0.91	0.86	0.80-0.91	0.03	-0.07 to 0.13	.528
Δ AR	0.03	-0.11 to 0.17	0.19	0.09-0.28	0.16	-0.01 to 0.32	.066

CI, confidence interval; LD, latissimus dorsi; PM, pectoralis major; TM, teres major; DM, deltoid muscle.

Fixed effects were complaints at follow-up (persistent/reduced complaints), moment (baseline/follow-up), moment \times complaints.

P values in bold are significant ($\alpha = 0.05$).

Table III Mean agonistic (EMG_{IP}) and antagonistic (EMG_{OP}) activity at baseline and follow-up

Complaints after follow-up		Baseline		Follow-up	
		Mean (μ V)	SD	Mean (μ V)	SD
Persistent complaints					
LD	EMG_{IP}	14	7.2	15	6.2
	EMG_{OP}	2.0	0.93	0.92	0.39
TM	EMG_{IP}	17	8.7	14	12
	EMG_{OP}	9.0	6.1	4.0	1.9
PM	EMG_{IP}	32	22	24	17
	EMG_{OP}	5.2	4.6	1.6	1.1
DM	EMG_{IP}	44	52	17	15
	EMG_{OP}	3.1	2.4	1.7	1.7
Reduced complaints					
LD	EMG_{IP}	17	13	14	13
	EMG_{OP}	1.7	1.0	3.4	4.3
TM	EMG_{IP}	18	9.2	22	16
	EMG_{OP}	5.7	3.9	12	8.5
PM	EMG_{IP}	27	16	29	22
	EMG_{OP}	4.7	3.7	4.0	4.1
DM	EMG_{IP}	36	22	42	60
	EMG_{OP}	6.3	3.6	1.9	1.7

SD, standard deviation; LD, latissimus dorsi; EMG_{IP} , electromyograph agonistic in-phase activation; EMG_{OP} , electromyograph antagonistic out-of-phase activation; TM, teres major; PM, pectoralis major; DM, deltoid muscle.

may influence whether patients develop adductor co-contraction. However, because it was not our goal to prove causal relationships between adductor co-contraction and complaints persistence, possible confounding by received therapy is not an issue.

To explore whether adductor co-contraction and complaints in SAPS are causally related, we suggest a placebo-controlled intervention study with, for example, EMG-guided exercise of adductors (eg, humeral depressor exercise).³¹ Furthermore, to gain insight into the underlying mechanism, the association between adductor co-contraction and proprioception may be assessed as well as the association between adductor co-contraction and aging.

Conclusion

The current prospective cohort comparing patients with SAPS at baseline and after nearly 4 years of follow-up showed that increased co-contraction of the LD and TM is associated with a favorable clinical course of SAPS. This finding may be explained by the beneficial effect of adductor co-contraction in widening of the subacromial space.^{15,26} These results could open a window for research into muscle-specific physical therapy in SAPS.

Disclaimer

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