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Clinical Research

Compensatory Movement Patterns Are Based on Abnormal Activity of the Biceps Brachii and Posterior Deltoid Muscles in Patients with Symptomatic Rotator Cuff Tears

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Abstract

Background Abnormal movement patterns due to compensatory mechanisms have been reported in patients with rotator cuff tears. The long head of the biceps tendon may especially be overactive and a source of pain and could induce abnormal muscle activation in these patients. It is still unknown why some patients with a rotator cuff tear develop complaints and others do not.

Questions/purposes (1) Which shoulder muscles show a different activation pattern on electromyography (EMG) while performing the Functional Impairment Test-Hand and Neck/Shoulder/Arm (FIT-HaNSA) in patients with a symptomatic rotator cuff tear compared with age-matched controls with an intact rotator cuff tear? (2) Which shoulder muscles are coactivated on EMG while performing the FIT-HaNSA?

Methods This comparative study included two groups of people aged 50 years and older: a group of patients with chronic symptomatic rotator cuff tears (confirmed by MRI

This work was conducted at the University Medical Center Groningen, Groningen, the Netherlands.

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Wolters Kluwer

or ultrasound with the exclusion of Patte stage 3 and massive rotator cuff tears) and a control group of volunteers without shoulder conditions. Starting January 2019, 12 patients with a chronic rotator cuff tear were consecutively recruited at the outpatient orthopaedic clinic. Eleven age-matched controls (randomly recruited by posters in the hospital) were included after assuring the absence of shoulder complaints and an intact rotator cuff on ultrasound imaging. The upper limb was examined using the FIT-HaNSA (score: 0 [worst] to 300 seconds [best]), shoulder-specific instruments, health-related quality of life, and EMG recordings of 10 shoulder girdle muscles while performing a tailored FIT-HaNSA.

Results EMG (normalized root mean square amplitudes) revealed hyperactivity of the posterior deltoid and biceps brachii muscles during the upward phase in patients with rotator cuff tears compared with controls (posterior deltoid: 111% ± 6% versus 102% ± 10%, mean difference -9 [95% confidence interval -17 to -1]; p = 0.03; biceps brachii: 118% ± 7% versus 111% ± 6%, mean difference -7 [95% CI -13 to 0]; p = 0.04), and there was decreased activity during the downward phase in patients with rotator cuff tears compared with controls (posterior deltoid: 89% ± 6% versus 98% ± 10%, mean difference 9 [95% CI 1 to 17]; p = 0.03; biceps brachii: 82% ± 7% versus 89% ± 6%, mean difference 7 [95% CI 0 to 14]; p = 0.03). The posterior deltoid functioned less in conjunction with the other deltoid muscles, and lower coactivation was seen in the remaining intact rotator cuff muscles in the rotator cuff tear group than in the control group.

Conclusion Patients with a symptomatic rotator cuff tear show compensatory movement patterns based on abnormal activity of the biceps brachii and posterior deltoid muscles when compared with age-matched controls. The posterior deltoid functions less in conjunction with the other deltoid muscles, and lower coactivation was seen in the remaining intact rotator cuff muscles in the rotator cuff tear group than the control group.

Clinical Relevance This study supports the potential benefit of addressing the long head biceps tendon in the treatment of patients with a symptomatic rotator cuff tear. Moreover, clinicians might use these findings for conservative treatment; the posterior deltoid can be specifically trained to help compensate for the deficient rotator cuff.

Introduction

Degeneration of the rotator cuff tendon might lead to the development of rotator cuff tears, which can result in pain and limited function [10]. Some patients have severe and lasting functional limitations, while others experience only a small period of discomfort and milder symptoms by adapting to shoulder function limitation. There are indications that the long head of the biceps tendon plays an important role in patients with rotator cuff tears because it is the one remaining structure preventing the humeral head from migrating [18, 29]. The cross-sectional area of the tendon is often enlarged in patients with a massive rotator cuff tear (MRCT), defined as more than two tendons involved and/or more than 5-cm retraction, which adds to the idea that the long head of the biceps tendon adapts its function [30]. A previous electromyography (EMG) study showed that the biceps tendon is activated in patients with a rotator cuff tear, although that study was conducted in individuals with rotator cuff tears of different sizes and the control group consisted of young people with no shoulder symptoms [9, 13, 14]. In one of these studies, increased activity of the middle and posterior deltoid was seen in patients with an MRCT [9]. It is thought that it serves as compensation for the loss of abduction torque of the supraspinatus.

In patients with resolving pain after a rotator cuff tear, a change in the activation and collaboration of the surrounding shoulder muscles to compensate for the insufficient rotator cuff is proposed [24, 12]. Cadaveric studies mention increased strain on the deltoid muscle [6]. The mechanism of this is not well understood [20]. Also, the exact role of the long head of the biceps tendon is not clarified—whether it buckles and impinges [2] or serves as a depressor and becomes overloaded and painful [4, 14]. The activity of the shoulder girdle muscles has been studied before with EMG [8, 9, 13, 26, 27], but evidence of differences between patients with a symptomatic rotator cuff tear and controls remains limited [27]. Case-control studies on this topic have been conducted, but with young healthy controls instead of same-age peers of patients with degenerative changes in the shoulder [9, 16]. Additional flaws noted in other studies were the lack of sample size, different rotator cuff tear sizes, tests not resembling daily activities [9, 27], and failure to accommodate age- and sex-related nerve changes [5, 19].

We therefore asked: (1) Which shoulder muscles show a different activation pattern on EMG while performing the Functional Impairment Test-Hand and Neck/Shoulder/Arm (FIT-HaNSA) in patients with a symptomatic rotator cuff tear compared with age-matched controls with an intact rotator cuff tear? (2) Which shoulder muscles are coactivated on EMG while performing the FIT-HaNSA?

Patients and Methods

Design

This was a comparative study conducted between January 2019 and August 2019. Our study compared a group of patients aged 50 years or older who had chronic symptomatic rotator cuff tears and an age-matched control group of volunteers without shoulder conditions. We obtained written informed consent from all participants, and the study was approved by the institutional review board of the University Medical Center Groningen (UMCG) (no. 2018/617) and registered in the Dutch Registry on research involving humans (no. NL68208.042.18). The study was conducted according to the principles of the Declaration of Helsinki and in conformity with the Medical Research Involving Human Subjects Act and other guidelines, regulations, and laws. The study met the Good Clinical Practice standard, and the Strengthening the Reporting of Observational Studies in Epidemiology guidelines were followed [32].

Participants

Rotator Cuff Tear Group

Patients with symptomatic, chronic degenerative rotator cuff tears (confirmed by MRI or ultrasound by an experienced musculoskeletal radiologist) were consecutively recruited at the outpatient clinic at the Orthopaedic Department of University Medical Center Groningen (UMCG). The rotator cuff tear group had been treated nonoperatively with subacromial injections for at least 3 months and physiotherapy using a standard protocol. In addition to explaining the cause of the symptoms and the rehabilitation protocol, the physiotherapist advised about activities of daily living. Passive glenohumeral and scapulothoracic movements were performed, and static and dynamic exercises were started. The aim of these exercises was to improve the glenohumeral and scapulothoracic musculature. Poor posture was corrected. In weeks 4 to 6, exercises were gradually increased, and deltoid training was started. In weeks 6 to 12, rehabilitation was aimed at further optimization of mobility and strength regeneration of the remaining cuff and deltoid muscles. Physiotherapy was continued until patients reached an optimum ROM and improved strength was achieved. If complaints persisted, patients were referred by their general practitioner to the outpatient orthopaedic clinic. We excluded participants younger than 50 years and those with symptomatic glenohumeral or acromioclavicular osteoarthritis based on examination and radiographs, Patte Stage 3 tears, MRCTs, a positive Hornblower test [7], previous surgery of the same shoulder, neurological deficits afflicting the arm, other diseases causing shoulder impairment, rheumatoid arthritis, and cervical spine conditions.

Starting in January 2019, 16 patients with a chronic rotator cuff tear were consecutively identified at the outpatient clinic. The following patients were excluded: one patient had a history of previous ipsilateral proximal humeral fracture, one had a congenital collagen disease, and another one had an MRCT. In total, 13 eligible candidates were recruited, and after one patient withdrew after reading the information brochure, 12 participants remained. All patients in the rotator cuff tear group had a tear of the supraspinatus tendon, Stage 1 or 2 according to the Patte classification. Additional small partial tears and one full tear of the subscapularis tendon and infraspinatus tendon were seen with inevitable subluxation of the biceps tendon.

Control Group

A total of 11 controls volunteered by responding to posters and flyers hanging at several public areas throughout UMCG; they were matched by age to patients in the rotator cuff tear group and consecutively included. Exclusion criteria were any previous surgery of the same shoulder, neurological deficits affecting the arm, other diseases causing shoulder impairment, rheumatoid arthritis, and cervical spine conditions. Before this visit, control participants with no shoulder symptoms in their dominant arm were examined with ultrasound by an experienced musculoskeletal radiologist at our institution to rule out asymptomatic rotator cuff tears or other shoulder abnormalities.

After providing written informed consent, all participants made an appointment at the clinical neurophysiology laboratory of UMCG to undergo tests, complete questionnaires, and undergo a physical examination by an unblinded research team (including the first author [EJDV] on every examination).

Functional Assessment: FIT-HaNSA and Questionnaires

The functional status of the upper limb was assessed using the FIT-HaNSA (score: 0 [worst] to 300 seconds [best] function). The test is based on activities of daily living and is extensively used in upper limb research. It is considered a reliable and valid test for assessing patients with shoulder conditions [8, 9, 15, 17]. As detailed by MacDermid et al. [17], the test consists of three subtasks. Task 1 involves consecutively lifting three 1-kg weights between two shelves, one positioned at the level of the participant's anterior superior iliac spine and a second 25 cm above. Task 2 differs in that one shelf is positioned at eye level and the second is 25 cm below. Task 3 involves screwing and unscrewing bolts on a plate positioned overhead. Participants are required to perform each task either for 300 seconds or until one of the criteria for stopping is met (pain or inability to proceed because of weakness).

A physical examination was additionally conducted, which included the Constant Murley score (CMS), a shoulder-specific score that ranges from 0 to 100 points if there are no complaints and/or deficits (minimum clinically important difference [MCID] 10.4 points), and the Hornblower test for the teres minor muscle [7]. Additional questionnaires were VAS-pain (0 to 100 points for the most shoulder pain) and the Western Ontario Rotator Cuff (WORC) Index [33], which is a disease-specific quality-of-life measurement tool for patients with rotator cuff disease (0 to 2100 points if there are no complaints [MCID -282.6 points]); and the EuroQol-5D, which is a generic health-related quality-of-life instrument with a descriptive system (0 to maximum 100 points for best quality of life) [31].

Functional Assessment: Electromyography

Bipolar surface cup electrodes were used for superficial muscles [22] in a standardized manner parallel to the muscle fibers according to previously described anatomic criteria [25]. All electromyographic examinations and functional tests were performed by one examiner (EJDV) and supervised by a senior neurophysiologist (JHvdH), both of whom were unblinded to rotator cuff status. Monopolar needle electrodes (Ambu A/S, Ballerup, Denmark) were used for intramuscular recording of the activity of the supraspinatus, infraspinatus, and subscapularis muscles. Needle electrodes were inserted aseptically according to the technique described by Basmajian and De Luca [1]. Adequate placement of the electrodes was determined with manual muscle testing, using the previously described tests for each individual muscle [11]. The quality of the recorded muscle activity was checked to ensure that signal-to-noise ratios were correct; poor-quality signals were excluded from analysis. Test-retest was judged to be unnecessary based on previous studies [8, 9].

All electrodes were connected to a 44-channel EEG headbox amplifier/AD converter (Schwarzer AHNS, Heilbronn, Germany) with 100 MOhm input impedance, < 10 kOhm electrode impedance, common mode rejection ratio > 100 dB at 50/60 Hz, sample rate of 1 KHz, band-pass filter of 0.07 Hz and 300 Hz, and 20-bit AD conversion. Signal acquisition, post processing, and analysis were performed on a software system (Onafhankelijke Software Groep, Kontich, Belgium) with BrainRT V3.1 (patch pack 5, build 4201). Raw data were subsequently processed offline using Matlab (R2019a, MathWorks Inc, Natick, MA, USA).

Testing Protocol

EMG was recorded while the participants performed an adjusted Task 1 of the FIT-HaNSA for 1 minute, so that sufficient repetitive movements were recorded [8]. Synchronized video at 30 frames per second (Sony EP580, Nihonbashi, Tokyo, Japan) was recorded in conjunction with the EMG data, which enabled phase definition for analyzing and determining the shelf contact time.

Data Management

The signals of the 10 remaining cycles were further processed by applying the root mean square (RMS) (window set 100 ms) [3, 21]. This smooths the signals and makes them positive. We subsequently calculated mean EMG amplitude for each muscle at the group level and normalized to the mean, set to 100%. Because amplitude fluctuates over time, this may result in numbers above and below 100%. Subsequent comparisons between groups were performed by dividing the signals into phases, with exclusion of the shelf contact time expressing the outcome as percentages [8, 9]. The cycle was further averaged with time normalization, resulting in an average activation profile. After screening of the final dataset, we removed outliers based on inconsequential data. We chose the RMS EMG protocol because it reflects a mean activation of a chosen period (phase up and phase down in this study). This is in contrast to other methods where percentages of the maximum voluntary contraction are used, which are less reliable or appropriate for shoulder conditions [9]. Moreover, this is not useful in a testing set-up reflecting daily life.

Primary and Secondary Outcomes

Our primary study outcome was muscle activation in patients with symptomatic rotator cuff tears using EMG measurements while performing the FIT-HaNSA test. The secondary outcome was the evaluation of coactivation of the shoulder muscles on EMG, while performing the FIT-HaNSA test by calculating the Pearson coefficient between activation profiles.

Sample Size and Statistical Analysis

Based on the study of Hawkes et al. [9], who used the same FIT-HaNSA protocol for assessment, we calculated a sample size of nine in each group to compare two-mean, two-sample, two-sided equality with an alpha of 5% and power of 0.80. This was based on a score of 100% on Task 1 for the control group and 60% for the rotator cuff tear group, with an SD of 30 and a sampling ratio of 1. Considering a potential loss to follow-up of 20%, we included at least 22 patients.

To quantify the coactivation of the shoulder muscles, we calculated Pearson correlation coefficients for each combination of muscles in each group [23]. This method has sensitivity to detect similarities in the activation pattern, and $r > 0.70$ is generally considered to indicate a strong, positive relationship [34]. A comparison between muscle groups was deemed of no further benefit because a previous study showed no differences [9].

SPSS statistical software (version 20.0; IBM, Armonk, NY, USA) was used for data compilation and statistical analyses. Demographic and clinical characteristics are presented as proportions for discrete variables and mean ± SD for continuous variables.

After checking for normal distribution and due to small numbers, we decided to present the other clinical outcomes (questionnaires and scores) as median (interquartile range) and mean difference (95% confidence interval). Differences between patients with a rotator cuff tear and control participants were tested using the Mann-Whitney test for non-categorical variables and the Fisher exact test for categorical data.

After confirming normal data distribution (Shapiro-Wilk test), the EMG results have been expressed as the mean ± SD. To minimize Type 1 errors, we performed a multivariate ANOVA (MANOVA) to look for significant differences between groups for both phases.

We assessed the statistical significance of differences between participants on the coactivation with a paired t-test. The Benjamini-Hochberg procedure was employed to control for the false discovery rate and showed that p values < 0.05 were considered significant. After removing outliers on EMG data (two patients in the rotator cuff tear group had unsuitable and distorted results), we were able to use the EMG results of 10 patients in the rotator cuff tear group and 11 in the control group for further analysis.

Patient Characteristics

Patients in the rotator cuff tear group had a mean (range) age of 65 ± 2 years (52 to 83), which was comparable to that of the control participants with a mean age of 61 ± 2 years (50 to 72; $p = 0.29$) (Table 1). The rotator cuff tear group had impaired shoulder function reflected in a restricted ROM and a median VAS shoulder pain of 55 (IQR 50). Moreover, the rotator cuff tear group reported a lower quality of life compared with the control

Table 1. Patient characteristics

Characteristics	Rotator cuff tear group (n = 12)	Control group (n = 11)	p value
Mean age in years ± SD	64.9 ± 2.5	61.2 ± 2.4	0.29[a]
Sex, n			
Male	6	6	0.48[b]
Female	6	5	
Investigated arm, n			
Left	4	3	0.55[b]
Right	8	8	
Smoking, n	1	4	0.16[b]
Diabetes, n	0	1	0.48[b]
Rotator cuff tear aspects	Retraction: 10-35 mm Width: 10-25 mm		
SSP, n	7		
SSP and SSC[c], n	Lafosse Type I: 3 Lafosse Type III: 1		
SSP and ISP, n	1		
Patte stage, n			
1	6		
2	6		
3	0		
Ultrasound, n	3	11	
MRI, n	9	0	

[a] t-test, as normal distributed.
[b] Fisher exact test.
[c] Lafosse classification of subscapularis tendon tears; SSP = supraspinatus; SSC = subscapularis; ISP = infraspinatus.

group (EuroQol-5D-5L scores: rotator cuff tear group median 71 [IQR 33]; control group median 87 [IQR 20]; mean difference 20 [6 to 33]; p = 0.02). The rotator cuff tear group showed impaired shoulder function with scores lower on the mean FIT-HaNSA than the control group (rotator cuff tear group median 137 [IQR 93] seconds; control group median 300 [0] seconds [maximal score]; mean difference 147 seconds [95% CI 106 to 189]; p < 0.001). On all three FIT-HaNSA tasks, participants in the rotator cuff tear group scored lower than those in the control group. Also, the rotator cuff tear group had lower CMS and WORC scores compared with the control group. (CMS: rotator cuff tear group median 52 [IQR 37], control group median 100 [IQR 8], mean difference 42 [95% CI 30 to 54]; p < 0.001; WORC: rotator cuff tear group median 1138 [IQR 919], control group median 81 [IQR 280], mean difference -896 [95% CI -1247 to -544]; p < 0.001) (Table 2).

Results

EMG Activation

EMG revealed hyperactivity of the posterior deltoid and biceps brachii muscles during the upward phase in patients with rotator cuff tears compared with controls (posterior deltoid: 111% ± 6% versus 102% ± 10%, mean difference -9 [95% CI -17 to -1]; p = 0.03; biceps brachii: 118 %± 7% versus 111% ± 6%, mean difference -7 [95% CI -13 to 0]; p = 0.04)

Table 2. Clinical and questionnaire scores

Parameter	RCT group, median (IQR)	Control group, median (IQR)	Mean difference (95% CI)	p value[a]
Anteflexion in °	125 (78)	170 (10)	40 (11 to 69)	**0.01**
Retroflexion in °	50 (35)	70 (0)	14 (1 to 27)	**0.03**
Abduction in °	110 (63)	170 (30)	44 (9 to 80)	**0.02**
External rotation in °	48 (85)	70 (10)	23 (4 to 43)	**0.05**
Internal rotation, number of patients reaching each level				
Gluteal	2	1	NA	0.49
L5	5	4		
T12	5	6		
FIT-HaNSA Task 1 score	214 (147)	300 (0)	83 (31 to 136)	**< 0.001**
FIT-HaNSA Task 2 score	68 (87)	300 (0)	206 (155 to 257)	**< 0.001**
FIT-HaNSA Task 3 score	108 (170)	300 (0)	154 (81 to 227)	**< 0.001**
Average score all 3 tests (0-300, worst to best score)	137 (93)	300 (0)	147 (106 to 189)	**< 0.001**
Constant-Murley score (0-100 worst to best score)	52 (37)	100 (8)	42 (30 to 54)	**< 0.001**
VAS-pain (0 -100 no pain to worst pain)	55 (50)	0 (6)	-49 (-69 to -29)	**< 0.001**
Total WORC (0-2100: best to worst score)	1138 (919)	81 (280)	-896 (-1247 to -544)	**< 0.001**
% WORC score	46 (69)	96 (13)	43 (26 to 59)	**< 0.001**
Physical symptoms (0-600, best to worst score)	359 (234)	39 (60)	-287 (-387 to -188)	**< 0.001**
Sports and recreation (0-400, best to worst score)	252 (188)	5 (55)	-204 (-282 to -127)	**< 0.001**
Work (0-400, best to worst score)	297 (113)	17 (50)	-244 (-311 to -175)	**< 0.001**
Lifestyle (0-400, best to worst score)	189 (224)	5 (80)	-194 (-272 to -118)	**< 0.001**
Emotions (0-300 best to worst score)	91 (155)	7 (35)	-88 (-150 to -26)	**< 0.001**
EuroQol-5D-5L score (0-100 worst to best score)	71 (33)	87 (20)	20 (6 to 33)	**0.02**

[a] p values calculated with a non parametric test (Mann-Whitney U test); NA = not applicable; FIT-HaNSA = Functional Impairment Test-Hand and Neck/Shoulder/Arm; CMS = Constant Murley score; WORC = Western Ontario Rotator Cuff Index.

Table 3. Differences in normalized EMG amplitudes between groups in the upward phase (phase 1)

Muscle	RCT group[a], mean ± SD	Control group[b], mean ± SD	Mean difference (95% CI)	p value[c]
SSP	103 ± 12	106 ± 7	3 (-6 to 12)	0.48
ISP	107 ± 8	106 ± 5	-2 (-8 to 5)	0.62
SSC	110 ± 9	108 ± 8	-2 (-10 to 6)	0.61
LD	106 ± 10	103 ± 5	-3 (-10 to 4)	0.39
PM	112 ± 9	110 ± 14	-1 (-13 to 10)	0.80
UT	126 ± 18	123 ± 15	-3 (-19 to 13)	0.71
PD	111 ± 6	102 ± 10	-9 (-17 to -1)	0.03[d]
MD	116 ± 10	111 ± 10	-5 (-14 to 5)	0.33
AD	118 ± 9	118 ± 9	0 (-8 to 9)	0.95
BB	118 ± 7	111 ± 6	-7 (-13 to 0)	0.04[d]

For the SSP, ISP, and SSC in the RCT group, the values are missing for one patient because of complaints about needles but the other EMG outcomes could be used.

[a] Rotator cuff tear group (n = 10); 10 cycles

[b] Control group (n = 11); 10 cycles

[c] Based on a MANOVA test.

[d] $p < 0.05$ (statistically significant); (flow in text with acronym expansions). SSP = supraspinatus; ISP = infraspinatus; SSC = subscapularis; LD = latissimus dorsi; PM = pectoralis major; UT = upper trapezius; PD = posterior deltoid; MD = middle deltoid; AD = anterior deltoid; BB = biceps brachii.

(Table 3). During the downward phase, there was decreased activity in patients with rotator cuff tears compared with controls (posterior deltoid: 89 ± 6% versus 98% ± 10%, mean difference 9 [95% CI 1 to 17]; p = 0.03; biceps brachii: 82 ± 7% versus 89 ± 6%, mean difference 7 [95% CI 0 to 14]; p = 0.03) (Table 4). The mean activation patterns of the posterior deltoid and biceps brachii of both groups are depicted as a line over time (Fig. 1A-D). In the rotator cuff tear group, contraction of the biceps brachii started early, with a high peak in the upward phase and declining at the end of the upward phase (Fig. 1A) compared with the control group (Fig. 1B). Contraction of the posterior deltoid started even earlier in the upward phase and declined at the end of the upward phase in the rotator cuff tear group (Fig. 1C) compared with the control group (Fig. 1D).

Table 4. Differences in normalized EMG amplitudes between groups in the downward phase (phase 2)

Muscle	RCT group[a], mean ± SD	Control group[b], mean ± SD	Mean difference (95% CI)	p value[c]
SSP	98 ± 12	94 ± 7	-3 (-13 to 6)	0.46
ISP	92 ± 8	94 ± 5	2 (-5 to 8)	0.58
SSC	90 ± 9	92 ± 8	2 (-5 to 10)	0.60
LD	94 ± 10	97 ± 5	3 (-4 to 10)	0.39
PM	89 ± 9	90 ± 14	1 (-10 to 13)	0.81
UT	74 ± 18	77 ± 15	3 (-13 to 19)	0.70
PD	89 ± 6	98 ± 10	9 (1 to 17)	0.03[d]
MD	84 ± 11	89 ± 10	5 (-5 to 15)	0.30
AD	81 ± 10	82 ± 9	0 (-9 to 9)	0.95
BB	82 ± 7	89 ± 6	7 (0 to 14)	0.03[d]

For the SSP, ISP, and SSC in the RCT group, the values are missing for one patient because of complaints about needles but the other EMG outcomes could be used.

[a] Rotator cuff tear group (n = 10); 10 cycles.

[b] Control group (n = 11); 10 cycles.

[c] Based on a MANOVA test;

[d] $p < 0.05$ (statistically significant); (flow in text with acronym expansions). SSP = supraspinatus; ISP = infraspinatus; SSC = subscapularis; LD = latissimus dorsi; PM = pectoralis major; UT = upper trapezius; PD = posterior deltoid; MD = middle deltoid; AD = anterior deltoid; BB = biceps brachii.

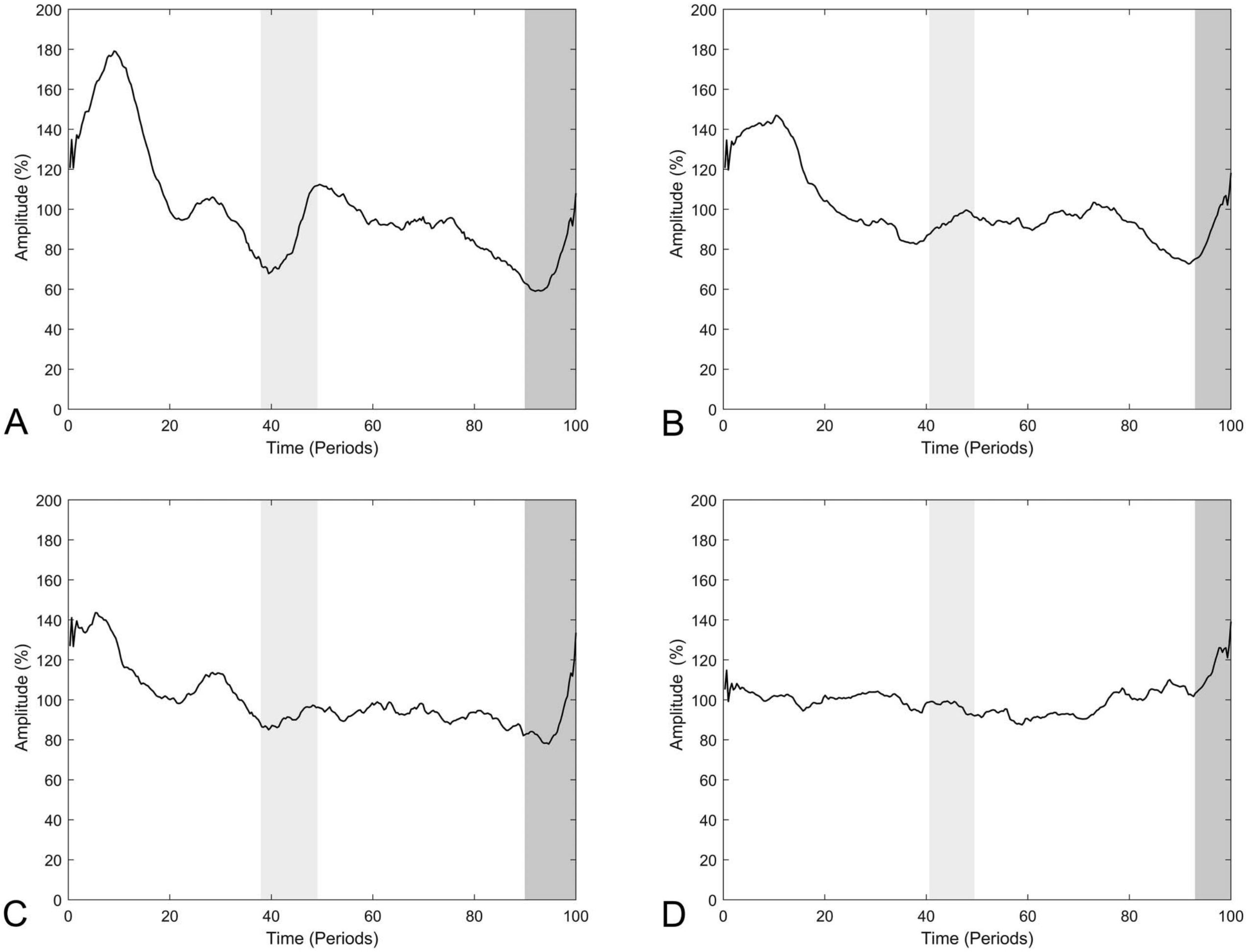

Fig. 1. A-D Average activation curves for the (**A**) biceps brachii muscle in the rotator cuff tear group, (**B**) biceps brachii muscle in the control group, (**C**) posterior deltoid muscle in the rotator cuff tear group, and (**D**) posterior deltoid muscle in the control group. The EMG signal amplitude is presented as a function of time. The light gray bars reflect activation during the upper shelf time and the dark bars reflect activation during lower shelf time.

Muscle Coactivation

In the rotator cuff tear group, the posterior deltoid functioned more independently, correlating poorly with the middle deltoid (R = 0.00; p = 0.94), latissimus dorsi (R = -0.07; p = 0.20), and biceps brachii (R = 0.10; p = 0.08) Seven muscle pairs in patients in the rotator cuff tear group showed a strong correlation (R > 0.70), and 15 strongly correlating muscle pairs were seen in the control group (Table 5). The anterior deltoid and middle deltoid were coactivated in both groups, but the posterior deltoid seemed to function less in conjunction with the other deltoid muscles in the rotator cuff tear group than in the control group. In the rotator cuff tear group, the posterior deltoid and biceps brachii had a slight relationship. By contrast, the latissimus dorsi showed a strong correlation with the anterior deltoid and middle deltoid muscles.

In the control group, activation of several rotator muscles (supraspinatus, infraspinatus, and subscapularis) were strongly correlated (supraspinatus with infraspinatus and infraspinatus with subscapularis). The rotator muscles were less coactivated in the rotator cuff tear group than in the control group; the supraspinatus was still coactivated with the infraspinatus, but the infraspinatus and subscapularis showed less coactivation. Most muscle pairs showed correlations, except for the posterior deltoid and middle deltoid, posterior deltoid and latissimus dorsi, and posterior deltoid and biceps brachii in the rotator cuff tear group (Appendix 1; Supplemental Digital Content 1, http://links.lww.com/CORR/A471). Additionally, in the control group, most muscle pairs had correlations except for the latissimus dorsi with posterior deltoid and the latissimus dorsi with upper trapezius.

Table 5. All muscle pairs with a highly correlated EMG activation pattern

Muscle	Rotator cuff tear group	Control group
AD with	MD, UT, LD	MD, PM, UT, ISP, SSC
MD with	UT, LD	PM, UT, ISP, SSC
PD with		BB
UT with	LD	PM
PM with		ISP, SSC
ISP with	SSP	SSP, SSC

Pearson correlation coefficient R > 0.70; AD = anterior deltoid; MD = middle deltoid; PD = posterior deltoid; PM = pectoralis major; UT = upper trapezius; LD = latissimus dorsi; BB = biceps brachii; SSP = supraspinatus; ISP = infraspinatus; SSC = subscapularis.
For full details on all R and p values, see Appendix 1.

Discussion

Patients with symptomatic rotator cuff tears can retain their shoulder function through compensatory mechanisms. These mechanisms are not fully understood. Previous studies were done in either a static setting or compared with young volunteers. Since functional impairment is the main complaint, it should be tested in a test setting resembling daily life. Muscles and nerves deteriorate with age, therefore, the function should be compared with age-matched controls.

We found that while executing the FIT-HaNSA protocol, patients with a rotator cuff tear compensated with hyperactivity of the posterior deltoid and biceps brachii muscles, as measured with EMG. Less coactivation was seen between the different deltoid muscle parts in the rotator cuff tear patients.

Clinicians might use these findings when treating patients with chronic rotator cuff tears conservatively. The posterior deltoid might be specifically trained to help compensate for a deficient rotator cuff. This study supports the potential benefit of addressing the long head biceps tendon in the treatment of patients with a symptomatic rotator cuff tear. The biceps muscle may be used as a humeral depressor, but this overactivity could induce pain at the long head of the biceps. These results also need to be weighed when considering tenotomy of the long head of the biceps tendon as a pain-relieving intervention in patients with irreparable rotator cuff tears. Future studies should investigate the effect of specific training of the posterior deltoid in patients with a rotator cuff tear. Also, further research on muscle activation and coactivation is needed in patients with a rotator cuff tear who become asymptomatic over time, and these could be compared with patients with a limited function whose rotator cuff tear remains painful.

Limitations

This study had several limitations. First, the examiner was not blinded, which could lead to a potential bias even though all patients were measured by the senior investigator (EJDV) and assisted by either one of the junior investigators (TES, TdG). Patients were included mostly based on MRI, although three were included based on ultrasound performed by an experienced musculoskeletal radiologist. Sex- and age-related changes exist in nerves [5, 19] and we tried to minimize these effects by matching on age and had an equal sex distribution. Due to the small groups, subgroup analysis was not deemed feasible. Although full MRCTs were excluded, all patients had sizable tears. It might be that smaller tears require less compensation. Testing more periscapular muscles could have been of added value. The EMG protocol and data monitoring were tested and proven in previous studies; therefore, no test-retest reliability was performed [9, 17]. Other potential confounders are the pain some patients had during the insertion of fine needles, which may have altered the movement of the upper limb during the measurements. It would be interesting to test both muscle bellies of the biceps because the medial head may have resulted in crossover signaling. Outliers in the EMG examination consisted of inverted measures or incomplete data, both most likely because of precarious instruments. However, we deemed that removal of this data was necessary.

EMG Activation

The muscle activation in the rotator cuff tear group was different from that in the control group, with hyperactivity of the posterior deltoid and biceps brachii in the rotator cuff tear group, especially when these participants started to lift a weight. Additionally, in the rotator cuff tear group, the other rotator cuff muscles were not hyperactive but showed less coactivation than those in the control group.

Despite the different study protocols, some results from previous studies could be reproduced, such as hyperactivity of the biceps brachii and posterior deltoid muscles on EMG. The previous shoulder EMG studies examined patients with simulated MRCTs who performed isometric tasks or who were also administered the FIT-HaNSA [8, 9, 28]. These studies saw the recruitment of the latissimus dorsi and teres major muscles as an adduction torque force for opposing deltoid force, thus attempting to stabilize the humeral head. We could not replicate the increased use of the latissimus dorsi in our group of patients with medium-sized rotator cuff tears who performed daily activities, although the pattern strongly correlated with that of the anterior and posterior deltoid muscles, suggesting more synergetic activation. One study suggests that in patients with a rotator cuff tear, the biceps brachii was overactivated because of flexion of the elbow while the arm was lifted to compensate for limited shoulder function [16]. In our results, the biceps brachii was active in the first part of the first phase and was therefore unlikely to contribute to hyperflexion of the elbow, which in our study occurred at the end of the first phase. This finding supports the idea that the long head of the biceps tendon functions as a depressor [14]. Our results are comparable to those of one of the first studies reporting on this topic, which showed more than 10% hyperactivity of the biceps brachii on EMG in 14 of 40 patients with a rotator cuff tear [13], although this was determined with a different measurement technique in patients with varying rotator cuff tear sizes. Hyperactivity of the biceps brachii was also seen by Hawkes et al. [9] in patients with MRCTs measured with the FIT-HaNSA. Kelly et al. [11] demonstrated that symptomatic patients with a posterosuperior cuff tear have an overactive subscapularis tendon. This was not repeated in the present study; our population included partial tears of the subscapularis tendon and one Lafosse Type 3 tear, which may have altered the activation.

Muscle Coactivation

Due to impaired rotator cuff function, other muscles compensate to centralize the humeral head during elevation but they do not work together. In the group with a rotator cuff tear, the biceps brachii and posterior deltoid were hyperactive but worked individually using different activation patterns. The posterior deltoid and biceps brachii were highly correlated (> 0.70) in the control group, an activation pattern that was not seen in the rotator cuff tear group. The deltoid muscles worked less synergistically in the rotator cuff tear group than in the control group.

Other studies have shown that activation of the subscapularis and infraspinatus compensate for minor supraspinatus tears, but these studies used simulated models that did not reflect activities of daily life, and some had a limited sample size [8, 11]. We did not find an increased activation of the subscapularis and infraspinatus in our rotator cuff tear group. Still, the muscle coactivation in the rotator cuff muscles in patients with a rotator cuff tear was changed. In the control group, rotator cuff muscle activation was strongly correlated. In the group with rotator cuff tears, we observed that, although the supraspinatus and infraspinatus were still coactivated, the subscapularis and infraspinatus showed less coactivation. The subscapularis is the most powerful muscle of the rotator cuff. If the subscapularis and infraspinatus are intact in patients with a supraspinatus tear, they could work together and centralize the humeral head into the socket. This lack of coactivation of the subscapularis could be one of the explanations of why function is limited in patients with rotator cuff tears. Future research should focus on whether selective training, especially of the subscapularis and the posterior deltoid, could lead to more synergistic muscle patterns, offering better pain relief and gain of function. An additional control group of asymptomatic rotator cuff tears would also be of added value.

Conclusion

Patients with impaired shoulder function due to symptomatic rotator cuff tears show compensatory movement patterns based on the abnormal activity of the biceps brachii and posterior deltoid muscles when compared with age-matched controls. The posterior deltoid functions less in conjunction with the other deltoid muscles, and lower coactivation is seen in the remaining intact rotator cuff muscles in the rotator cuff tear group than the control group. Clinicians might use these findings during conservative treatment of patients with chronic rotator cuff tears. The posterior deltoid might be specifically trained to help compensate for the deficient rotator cuff. This study supports the potential benefit of addressing the long head of the biceps tendon in the treatment of patients with symptomatic rotator cuff tears. Further research on muscle activation and coactivation is needed in patients with rotator cuff tears who become asymptomatic over time, and studies should compare these patients with those who have limited function and whose rotator cuff tear remains painful.

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