J Shoulder Elbow Surg (2017) 26, 497–505

Journal of
Shoulder and
Elbow
Surgery

www.elsevier.com/locate/ymse

The influence of induced shoulder muscle pain on rotator cuff and scapulothoracic muscle activity during elevation of the arm

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Background: Altered recruitment of rotator cuff and scapulothoracic muscles has been identified in patients with subacromial impingement syndrome. To date, however, the cause–consequence relationship between pain and altered muscle recruitment has not been fully unraveled.
Methods: The effect of experimental shoulder pain induced by injection of hypertonic saline in the supraspinatus on the activity of the supraspinatus, infraspinatus, subscapularis, trapezius, and serratus anterior activity was investigated during the performance of an elevation task by use of muscle functional magnetic resonance imaging in 25 healthy individuals. Measurements were taken at 4 levels (C6-C7, T2-T3, T3-T4, and T6-T7) at rest and after the elevation task performed without and with experimental shoulder pain.
Results: During arm elevation, experimentally induced pain caused a significant activity reduction, expressed as reduction in T2 shift of the IS ($P = .029$). No significant changes in T2 shift values were found for the other rotator cuff muscles or the scapulothoracic muscles.
Conclusions: This study demonstrates that acute experimental shoulder pain has an inhibitory effect on the activity of the IS during arm elevation. Acute experimental shoulder pain did not seem to influence the scapulothoracic muscle activity significantly. The findings suggest that rotator cuff muscle function (infraspinatus) should be a consideration in the early management of patients with shoulder pain.
Level of evidence: Basic Science Study; Kinesiology

Keywords: Experimental pain; rotator cuff; scapula; muscle functional magnetic resonance imaging; exercise; muscles; shoulder pain

Shoulder pain is a common complaint, and the lifetime prevalence reaches 66.7%, with women reporting shoulder pain more often than men.[32] Shoulder impingement symptoms (SISs) are present in 40% of those patients.[28,32,47] Altered muscle activation patterns of the rotator cuff and the

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The Ghent University Hospital Ethical Committee (Registration Number: B670201215743 - Study Number 2012/868) approved the protocol for this study.

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http://dx.doi.org/10.1016/j.jse.2016.09.005

scapulothoracic muscles have been found in patients with painful SIS,.[2,9,11,17,29-31,35,37,38] However, to date, it is not clear whether pain is the source of altered muscle activation patterns or whether pain arises secondary to alterations in the muscle activity patterns.

The use of experimental pain may be valuable to study the effect of acute pain on muscle recruitment and allows evaluation of the causative relationship between pain and dysfunction.[25,44] Experimental pain has some advantages over clinical pain because it creates a pain model with relatively consistent location, duration, and intensity of pain in contrast to the high between-subject variation and the heterogeneity of shoulder pain in clinical studies. The few studies of experimental pain in the shoulder region used electromyography (EMG) to investigate the influence of pain on muscle recruitment and activation.[1,18,42,43] The use of EMG as the primary method for evaluating the activity of the rotator cuff and scapulothoracic muscles in patients with shoulder pain has some limitations, including cross talk, variable signaling through subcutaneous tissue, difficulty with accurate electrode placement, and the physical movement of the muscle. Moreover, muscles that lie deeply, such as the rotator cuff muscles, can only be measured with fine-wire EMG; however, this fine-wire method is invasive and is limited to the activity of 1 motor unit.

An alternative technique that is able to evaluate muscle recruitment patterns is muscle functional MRI (mfMRI). mfMRI is a noninvasive technique based on the differences in water relaxation values (T2-relaxation) of the muscles,[5] is comparable with EMG for quantifying muscle activity in response to exercise, and overcomes the limitations of surface EMG.[16] The technique relies on an acute activity-induced increase in T2 relaxation times of muscle water, resulting from underlying metabolic reactions.[5] The shifts in T2 values upon exercise (T2 shift) relate to the amount of work performed by the muscle.[16] The advantages of mfMRI are that it can map the intermuscular recruitment patterns with a very high spatial accuracy, is noninvasive, and has a high sensitivity and specificity.[5,26,34] Unlike EMG, however, it cannot provide real-time information about the amount and timing of the underlying muscle activity. Because of its excellent spatiotemporal resolution, mfMRI can be used as a noninvasive evaluation of the function of muscles around the scapula, such as the rotator cuff and the serratus anterior (SA), that are challenging to evaluate with EMG. mfMRI has also been used to investigate the influence of experimental pain on spinal muscles.[3,6,15]

Only a few studies to date have used the mfMRI technique to evaluate the muscles around the shoulder region.[7,24,41,45] Cahoy et al[7] and Horrigan et al[24] evaluated the rotator cuff muscles before and after different exercises. Takeda et al[45] determined with mfMRI the best exercise (empty can, full can, and horizontal abduction) for strengthening the supraspinatus (SS) muscle, whereas Sheard et al[41] used mfMRI to investigate the SA muscle function during isometric upper limb exercise in individuals with neck pain and scapular dysfunction compared with healthy controls.

These 4 studies used mfMRI to investigate muscle function around the shoulder, but studies investigating differences between individuals with and without shoulder pain (experimental or clinical pain) are currently lacking. Therefore, the aim of this study was use mfMRI to examine the effect of experimentally induced pain on muscle activity of the rotator cuff and scapulothoracic muscles in healthy individuals when performing elevation in the scapular plane.

Materials and methods

Participants

The study recruited 25 healthy individuals (9 men 16 women). Candidates were excluded if they reported past or current neck or shoulder pain, if MRI was contraindicated, or if they performed upper limb training or overhead sports more than 6 hours weekly. The study participants were a mean age of 30.5 ± 12.5 years, a mean weight of 69 ± 12.9 kg, and a mean height of 173.5 ± 9.3 cm. Before taking part in the study, participants had to read and sign the informed consent.

Test procedure

All subjects were asked to avoid heavy overhead activities 48 hours before the testing took place. Participants were tested under 2 conditions: first without pain and then with experimental shoulder pain. MRIs were obtained at 3 different times: at rest, immediately after the performance of the exercise without pain, and immediately after the performance of the exercise while having shoulder pain. First, the subjects lay supine for 15 minutes, after which a resting MRI was obtained ("rest"). Then, subjects performed an exercise protocol consisting of an elevation exercise in the scapular plane outside the scanner room. Immediately after this exercise, the second MRI was taken ("post").

After a minimum of 45 minutes of rest, which is required to allow recovering of approximately 98% of the T2 shifts,[10] muscle pain was elicited by the injection of hypertonic saline into the SS muscle of the dominant arm. While having muscle pain, the subjects performed the same scapular elevation task, which was immediately followed by the third MRI ("postpain"). The difference in T2 before and after the elevation exercise, which is referred as the T2 shift, was measured for the infraspinatus (IS), subscapularis (SUB), trapezius, and SA muscles, as it indicates the magnitude of underlying metabolic muscle activity resulting from exercise.

Exercise protocol: arm elevation in the scapular plane

The subjects performed humeral elevation in the scapular plane (30° to the frontal plane) with the dominant arm. This exercise was chosen because this demands high activity of the rotator cuff and the scapulothoracic muscles. Participants were instructed to perform 3 sets of 10 repetitions, with 15 seconds of rest between the sets. The participant was standing and was asked to raise and lower the arm. The up and down movements both lasted 3 seconds without break at the top level (full elevation). A metronome was used to ensure appropriate timing, and feedback to reach the right plane (30°) was obtained by a pole that stood in the direction of the plane.

The amount of weight of the dumbbell used by the participants was determined from a pilot study in 30 subjects to define the appropriate weight for performing 3 sets of 10 repetitions, for men and women, divided in categories by body weight. The dumbbell weight for women was always 2 kg (independent of the weight of the subject, because we could not find differences in load between different body weight classifications), whereas the weight for men was allocated according to the individual's weight (3 kg, 4 kg, or 5 kg for 60-69 kg, 70-79 kg, and 80-89 kg, respectively). If the participant reported maximal exhaustion before the end of the 30 repetitions (and the exercise could no longer be performed with a good quality), the exercise was stopped and the MRI was obtained immediately.

Experimentally induced pain

Real-time ultrasound guidance was used to inject a bolus of 1 mL of hypertonic saline (5%) into the SS of the dominant arm. The location and volume of the hypertonic saline injection was chosen on the basis of experience from previous studies.[18,20,23,33,46] The distribution of pain after the hypertonic saline injection in the SS is known to be in front of the shoulder over the anterior part of the deltoid muscle, similar to that described in patients with SIS.[18] While the individual was seated, the injection zone was marked 3 cm lateral to the middle of the distance between C7 and the most lateral part of the acromion.[18] Fear (fear of injection, fear of pain, fear for the whole investigation), intensity of the induced pain, and fatigue were scored using the Numeric Rating Scale (NRS). Before the injection, subjects had to rate if they feared the injection, the fear of pain induced by the injection, from 0 (not at all fearful) to 10 (extremely fearful), and how painful they expected the pain injection to be.[27]

Pain intensity (0: no pain;10: worst possible pain) was verbally rated 30 seconds after the injection. If a participant reported a NRS of at least 4 of 10, the elevation task was started immediately; if it was below 4 of 10, an additional injection with 0.5 mL saline was given before the start of the exercise.[3,15] During the experiment, the subjects were asked to rate their pain at the start of each set, after 5 repetitions, and at the end of each set. After each set, the level of muscle fatigue was asked (0: no fatigue, 10: worst possible fatigue). At the end of the entire procedure, the subject was asked to rate the pain and to indicate the localization of pain on a body diagram.

Functional muscle MRI

A 3-Tesla Trio Tim scanner (Siemens, Erlangen, Germany) was used for the mfMRI protocol to assess changes in the relaxation time of muscle water (T2 relaxation time) as a result of muscle work during the elevation exercise. The amount of muscle activity can be assessed by quantifying shifts in T2 relaxation times and is expressed as the T2 shift.[34]

A combination of an 8-element spine, a 4-element neck, and a 6-element body matrix coil were used for image acquisition. The participant's position within the scanner was standardized before and after exercise to guarantee the same field of view and slice position before and after exercise. The participant was positioned supine onto the scanning table with his or her head closest to the magnet, head and neck in a neutral position and hips flexed to 45° (supported by foam wedges). The subjects were asked to lie on the scanning table with the top of their acromion as close as possible against the surface of the neck coil, which allowed for similar positioning in the magnet bore over repeated scans.

Each participant underwent a series of scanning sequences. First, a sagittal localizing sequence was taken to visualize the disc space intervals. After this, a T1 image (spin echo) and a T2 image (Carr-Purcell-Meiboom-Gill [CPMG] sequence) was obtained at 4 different levels parallel to the C6-C7, T2-T3, T3-T4, and T6-T7 intervertebral discs (axial slices). A T1 image (spin echo T1) was included because this image shows higher contrast than the T2-weighted image and allowed us to identify the regions of interest (ROIs) of the different muscle bellies more accurately on the T2-weighted image. After the exercise, the same T2 image (with the same CPMG sequence) was performed. The CPMG sequence parameters were repetition time of 2000 ms, echo times of 10.5-168 ms with steps of 10.5 ms (16 echos), field of view of 233 × 340 mm, and voxel size of 1. 3 × 1.3 × 4. 0 mm (total scan time was 5 minutes and 56 seconds).

Data analysis

The acquired images were converted into T2 maps for calculation of the mean transverse relaxation times (in ms) of the different ROIs using the T2Processor software (P. Vandemaele, Eng., Ghent Institute for Functional and Metabolic Imaging Universitair Ziekenhuis, Ghent, Belgium). The T2 value was calculated with the formula: $Sn = S0 \times \exp(-TE/T2)$; where *Sn* represents the signal intensity expressed in ms at a given echo time (*TE*) within the scanner's original signal intensity S0. In every condition (rest, post, and postpain) and for every slice, different ROIs were carefully selected (exclusion of nonmuscular tissue) for T2 analysis. The selection of the ROI was performed 3 times for each muscle, and the average T2 value was taken. The intrarater agreement of the T2 measures ranged from 0.925 to 0.987, depending on the muscles, as calculated by the intraclass correlation coefficient (3.1, 2-way random, average value). The muscles of interest were the SS, IS, SUB, upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and SA. Figs. 1-4 show

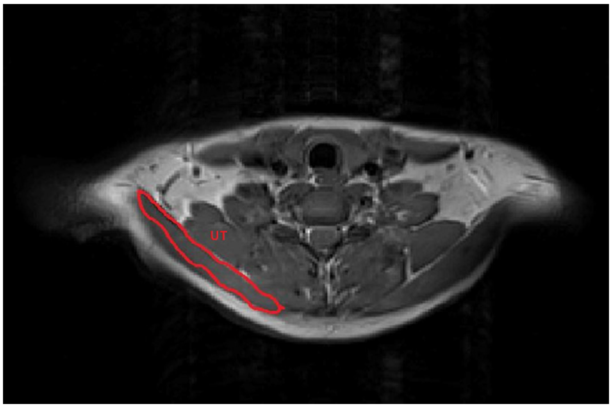

Figure 1 Region of interest (*red outline*) for the upper trapezius (*UT*) muscle in the T2-weighted (T2 map) image at the level parallel to C6-C7.

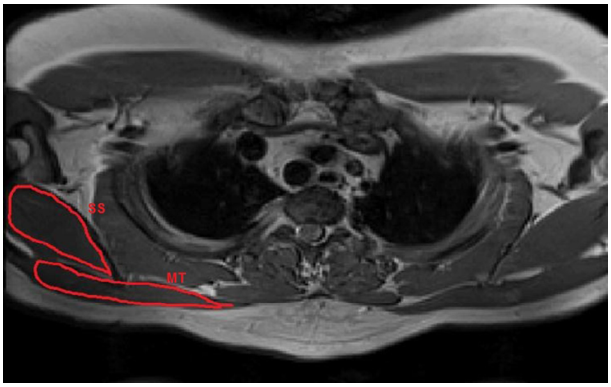

Figure 2 Region of interest (*red outline*) for the supraspinatus (*SS*) and middle trapezius (*MT*) muscles in the T2-weighted (T2 map) image at the level parallel to T2-T3.

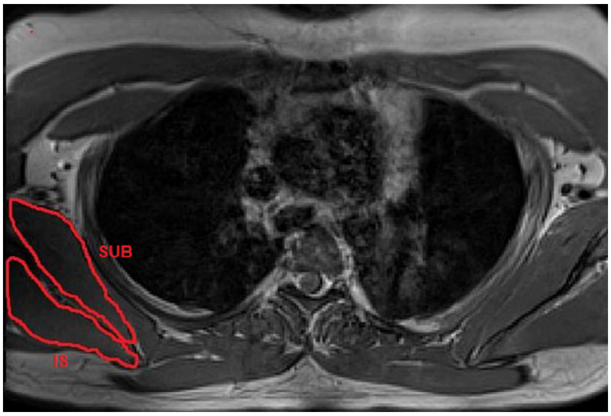

Figure 3 Region of interest (*red outline*) for the subscapularis (*SUB*) and infraspinatus (*IS*) muscles in the T2-weighted (T2 map) image at the level parallel to T3-T4.

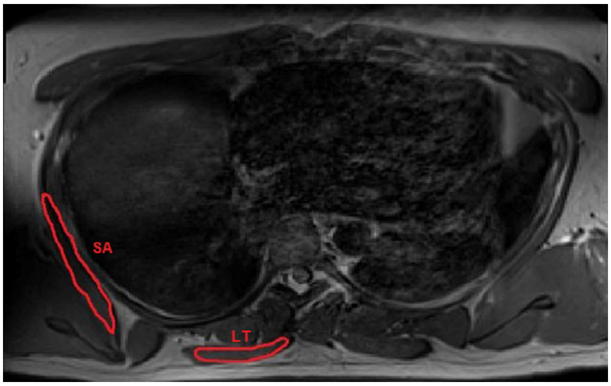

Figure 4 Region of interest (*red outline*) for the serratus anterior (*SA*) and lower trapezius (*LT*) muscle in the T2-weighted (T2 map) image at the level parallel to T6-T7.

the different ROIs of the muscles on each level parallel to the C6-C7, T2-T3, T3-T4, T6-T7 intervertebral discs on axial slices. The mean T2 values for each muscle were used for further analysis.

Statistical analysis

SPSS 22.0 software (IBM Corp., Armonk, NY, USA) was used for statistical analysis. Descriptive statistics expressed as mean ± standard deviation were calculated for fear of the induced pain, intensity of the induced pain, fatigue, and actual T2 values (ms) and T2 shifts (ms), which are defined as the difference between the postexercise and resting T2 values. The T2 shifts for muscle work during elevation in normal condition (T2 post – T2 rest) and in painful condition (T2 postpain – T2 rest) were calculated and used for further analysis. For each muscle, a paired sample *t* test was performed to determine whether there were significant differences in T2 shifts for that muscle between the condition "nonpain" and "pain." Also, a linear mixed model (with Bonferroni correction for post hoc tests) was used to evaluate possible differences for fatigue between different conditions (with and without pain) and different time points (after each exercise set). An α level of 0.05 was applied to all the data in determining significant differences.

Results

Fear of experimental shoulder pain

The NRS score was 0.8 ± 1.1 for fear of injection, 1.5 ± 1.5 for fear of pain and 1.2 ± 1.3 for fear for the whole investigation.

Pain intensity of experimental shoulder pain

Fig. 5 shows the pain intensity after the injection to induce experimental shoulder pain. Thirty seconds after the injection, the mean pain score intensity was 5.1 ± 1.4; thus, the participants started set 1 with a mean pain score of 5.1 ± 1.4. At the beginning of set 2, the pain intensity decreased to 4.8 ± 1.9 and further decreased to 4.0 ± 2.1 at the beginning of set 3. At the end of the entire procedure (after the last MRI) the patients reported an NRS score of 1.7 ± 1.7.

Fatigue

Mean scores for fatigue can be found in Table I. There was a significant condition × time interaction effect ($F = 4.848$, $P = .009$) for fatigue. Post hoc tests revealed that the fatigue increased significantly for nonpain and with pain after each exercise bout ($P = .006$). When the fatigue of each exercise bout was compared between conditions without pain and with pain, after exercise bout 1 the difference in fatigue score between the conditions was not significant ($P = .288$), whereas after bouts 2 and 3, there was a significant difference in the fatigue score between the conditions: with pain induction, the subjects reported a lower fatigue ($P = .048$) compared with the nonpain induction ($P = .002$).

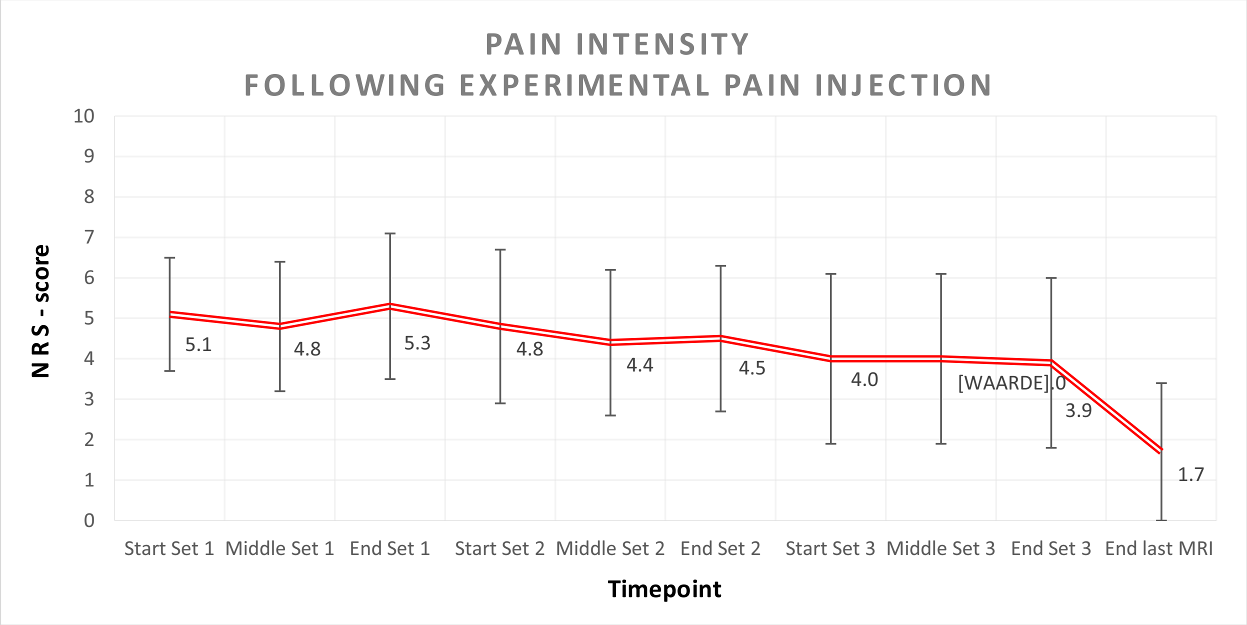

Figure 5 Pain intensity (0-10) according to the Numeric Rating Scale (*NRS*) after injection of hypertonic saline into the supraspinatus. Data are shown as the mean ± standard deviation (*range bars*).

Table I Muscle fatigue* after the exercise set without pain and with pain

Variable	Without pain Mean ± SD	With pain induction Mean ± SD
After exercise bout 1	3.9 ± 1.9	4.2 ± 1.8
After exercise bout 2	5.8 ± 2.0	5.2 ± 2.0
After exercise bout 3	7.4 ± 1.9	6.4 ± 1.7

SD, standard deviation.

* Fatigue was assessed using the Numeric Rating Scale (range, 0-10), with 0 indicating no fatigue and 10 indicating worst possible fatigue.

Table II Absolute T2 values for all muscles during the rest condition, the condition after the exercise (*Post*), and the condition after the exercise performed with pain (*Postpain*)

Muscle	Rest Mean ± SD, ms	Post Mean ± SD, ms	Postpain Mean ± SD, ms
Trapezius			
Upper (C6-C7)	38.7 ± 2.4	46.6 ± 5.0	45.1 ± 5.3
Middle (T2-T3)	39.8 ± 2.3	44.6 ± 4.2	44.7 ± 3.3
Lower (T6-T7)	35.6 ± 2.3	41.7 ± 3.0	41.3 ± 3.0
Serratus anterior (T6-T7)	40.3 ± 3.2	48.2 ± 5.7	47.4 ± 5.0
Infraspinatus (T3-T4)	47.2 ± 3.7	56.6 ± 6.0	54.6 ± 4.7
Subscapularis (T3-T4)	44.0 ± 3.3	49.2 ± 5.3	48.5 ± 4.4
Supraspinatus (T2-T3)	48.8 ± 3.9	61.8 ± 6.9	58.5 ± 4.2

SD, standard deviation.

mfMRI investigations

Mean T2 values for rest, postexercise, and postexercise in condition with pain can be found in Table II. The analysis displayed a significant difference in T2 shift for the IS between the nonpain and the pain condition ($P = .029$): the IS showed a decrease in T2 shift in response to experimentally induced shoulder pain. For the other muscles, no significant differences were found between the conditions. The absolute mean T2 values (ms) are reported in Table II, and the T2 shifts are visualized in Fig. 6.

Discussion

The aim of this study was to investigate the effect, by the use of mfMRI, of acute induced shoulder muscle pain on the rotator cuff as well as scapulothoracic muscle activity during humeral elevation of the arm in the scapular plane. The main finding was that a significantly decreased T2 shift of the IS was found in response to experimentally induced pain, whereas no change was found in the other rotator cuff muscles and the scapulothoracic muscles.

A notable finding of this study was that the amount of activity (estimated by the shift in T2 values) of the IS was influenced when acute experimental shoulder muscle pain was present: an inhibition of the IS activity occurred when elevation was performed in the scapular plane. The IS plays an important role in the shoulder joint because it is not only an external rotator but also stabilizes the humeral head during

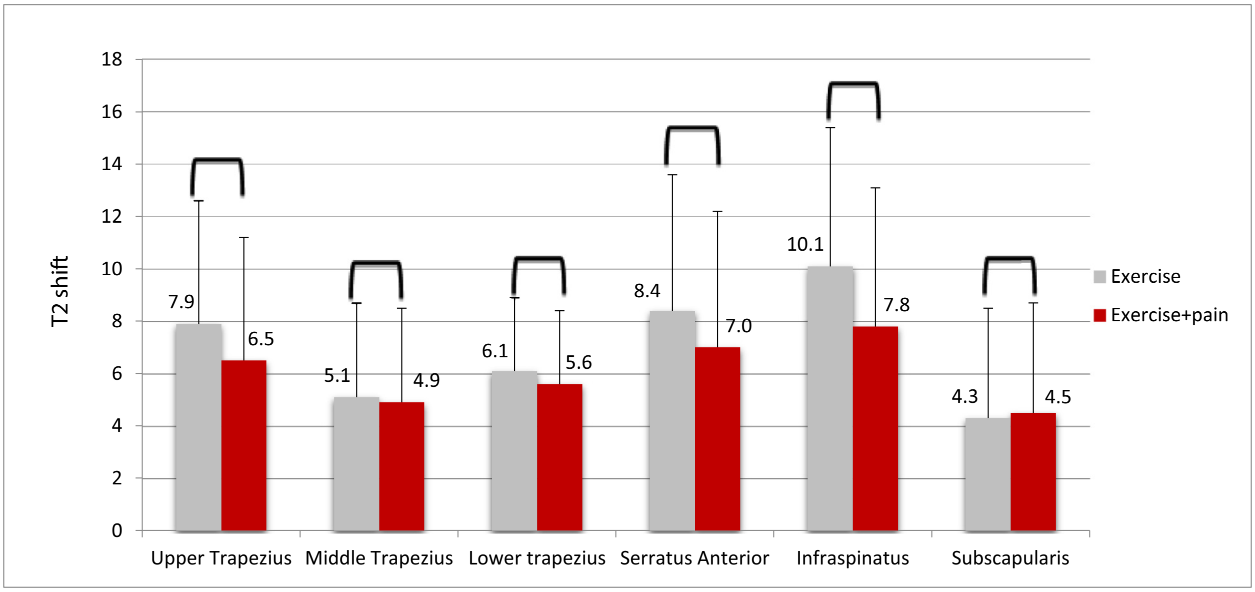

Figure 6 T2 shifts for the nonpain and pain conditions and *P* values for comparisons of the T2 shifts between the 2 conditions. Data are shown as the mean ± standard deviation (*range bars*). No values are given for the supraspinatus because this muscle was injected with saline and the saline might have changed the signal intensity of the injected muscle, and as a consequence, artificially influence the T2 values. $^{*}P < .05$ indicating statistical significance.

elevation of the arm. During elevation, the IS depresses the humeral head to avoid contact and impact with the coracoacromial arch.[21] Dysfunction or inhibition of the IS can result in insufficient humeral head depression during humeral elevation leading to shoulder impingement. So overall, these results show that acute shoulder pain may induce an alteration in rotator cuff muscle function (lowering IS function), which may lead to insufficient humeral head depression and a reduction of the functional subacromial space and thereby increase the risk of impingement and pain.[18] Although our study only shows a statistically significant difference in the IS T2 shift, it might not be the only major factor explaining pain in SIS.

Few studies have used experimental pain (after injections into the SS and the subacromial space) to investigate the effects of acute shoulder pain on glenohumeral muscle activity.[1,18,42,43] These studies all used EMG to evaluate the effect of experimental pain:

Diederichsen et al[18] found that experimentally induced pain in the SS caused a significant decrease in anterior deltoid and IS EMG activity during concentric abductions.

Sole et al[42] evaluated the effects of experimentally induced subacromial pain on the rotator cuff during concentric and eccentric humeral elevation. No significant effects on muscle activity were found during the concentric phase. During the eccentric phase, increased activity was found for the pain condition for the middle deltoid from 120° to 30° and decreased activity for IS from 60° to 0°. No significant differences were found for SUB and SS.

Stackhouse et al[43] demonstrated that acute experimental pain elicited a decline in external rotation muscle force and voluntary activation of the IS.

Bandholm et al[1] found that experimental muscle pain increased middle deltoid and IS muscle EMG activity during isometric and concentric contractions.

So in general, our results are in line with previous research that shows a decrease in IS EMG activity (except the study of Bandholm et al[1]) in response to acute experimental shoulder pain. Also, Wassinger et al[48] found that experimentally induced subacromial pain significantly reduced the strength of shoulder external rotation, which is also produced by the IS.

Remarkably, the current study found no differences in scapulothoracic muscle activity after the hypertonic saline injection. Other studies investigating the influence of experimentally induced pain on scapulothoracic muscle activity did find some differences in scapulothoracic muscle activity, but the results were overall conflicting.[1,18,42] In contrast with our study, Diederichsen et al[14] found a decrease in UT activity and an increase in LT activity after experimentally induced pain in the SS. Bandholm et al[1] also found an increase in LT activity during isometric and concentric contractions in response to acute experimental shoulder pain. Differences in study methods (EMG vs mfMRI) and tasks could be the reason the results of our study differed from those of the other studies.

Whether experimentally induced shoulder pain reproduces the same muscle activity changes as in people with SIS is unknown. The acute experimental shoulder pain will probably differ somewhat from that of clinical shoulder pain because changes in neurologic processing and function also occur with prolonged pain.[19] Several studies have investigated rotator cuff and superficial scapulothoracic muscle activity in patients with SIS during elevation exercises by means of EMG.[2,29,31,38]

Some authors have found rotator cuff muscle recruitment abnormalities in individuals with chronic SIS. These abnormalities have been linked to failure of the rotator cuff to center the humeral head in the glenoid during shoulder motion.[35,37] Our results are in line with the results of Reddy et al[37] and Myers et al.[35] Reddy et al[37] found that people with SIS demonstrated decreased rotator cuff activity, particularly of the IS muscle, during isotonic shoulder abduction in the scapular plane. The results of Myers et al[35] indicated that individuals with SIS showed rotator cuff and deltoid activation abnormalities during humeral elevation. Our results contrast with the results of Bandholm et al[2] and Roy et al,[38] who did not document abnormalities in rotator cuff activity in patients with SIS during isometric elevation[2] for the deltoid, IS, and SS, or a reaching task[38] for the IS and deltoid.

Different authors have investigated scapulothoracic activity during elevation of the arm. A recent study of Castelein et al[8] did not find differences in scapulothoracic activity (trapezius, SA, rhomboid major, and levator scapulae), except for the pectoralis minor, between patients with SIS and healthy controls during different elevation tasks in the scapular plane. Bandholm et al[2] and Roy et al[38] also did not find differences in superficial scapulothoracic activity in patients with SIS. Lin et al[29] showed higher UT and lower LT and SA activity in the SIS overhead athletes compared with the controls during an elevation task. Ludewig and Cook[31] found higher UT activity in patients with SIS, but only during the final 2 phases (60°-120°) of humeral elevation in the scapular plane in the 4.6-kg load condition. LT activity was increased in the group with SIS compared with the group without SIS in the final 2 phases. The SA demonstrated decreased activity in patients with SIS across all loads (no load, 2.3-kg load, and 4.6-kg load) and phases.

That all investigated muscles in the current study showed a decreased activity in the pain condition is remarkable. Nevertheless, the exercise performance in the nonpain and the pain condition remained the same; therefore, a load shift has to have occurred in other muscles to compensate for the decreased activity in the studied muscles. In this study, however, the reduction of the muscles was not compensated by an increase of the investigated synergistic or antagonistic muscles specific to the performed task. Hypothetically, other muscles that were not investigated, such as the prime mover deltoid, could have compensated for the reduced activity of the other muscles by increasing the activity to perform the same movement.

Although a change is present for the IS (response of reduction after pain induction), recent research suggests that sensorimotor changes in response to pain vary between individuals.[22] Multiple ways to achieve a goal (here: elevation task) involving different combinations of muscle activity exist. Because we saw large standard deviations in the T2 shifts in our study, there might indeed be an individual-specific motor control response in response to pain.

The findings suggest that rotator cuff muscle function (IS) should be a consideration in the early managing of patients with shoulder pain. Inhibition of the IS in the presence of acute subacromial pain may indicate an increased risk for increased glenohumeral translation, potentially exacerbating shoulder pain.

The conclusions of this study need to be interpreted according to the limitations of the study and the flaws of the study design. The current study included 25 individuals. Although this is a reasonable number, the female-to-male ratio (16:9) could have biased the results. In this study, the dumbbell weight was adjusted to sex and bodyweight. However, future studies should also consider adaptation of the dumbbell weight to body mass index, body fat percentage, age, and height.

A flaw of the current study design is that a no control group was included. The use of a control group that undergoes an injection of a nonpain-producing substance (eg, isotonic saline) would be interesting to eliminate whether changes in muscle activity were not caused by the injection of fluid rather than the pain. Also, in this study, analyzing the effect of acute pain on the SS was not possible because this muscle has been injected with saline, which may change the signal intensity and influence the T2 values.

Another study limitation is that only the influence of acute experimental pain was observed; the effect of chronic pain or acute traumatic pain might be different. Although a chronic pain induction would be of interest in reproducing SIS, it cannot be conducted because of ethical reasons. In addition, the current protocol only examined the acute effect of pain and did not evaluate the effect of this pain on later time points. The acute effect of experimental pain did not lead to changes in the scapulothoracic muscles. Compensatory changes of scapulothoracic muscles might possibly be present on later time points after the injection, with or without repetitive use of the affected shoulder.

The current study did not investigate the T2 shifts of the deeper lying scapulothoracic muscles, such as pectoralis minor, levator scapulae, and rhomboid major, because of issues with small cross-sectional area (determination of ROI was too difficult) and movement artefacts caused by respiration and pulsed streaming of the blood. Future research should also investigate the influence of pain on the other muscles than those investigated here.

Although the methodology, analysis, and interpretation of the results of the current study were similar to those of other published studies in this area[3,4,6,12-14,16,36,39,40] and give valuable and important information, it would also be interesting for future research to examine 3-dimensional distributions of muscle activity (T2 shifts) by using data of the whole muscles and combining the different axial layers.[26] This approach has been used by Kinugasa et al[26] and gives important information about areas of active muscle along transverse, longitudinal, and vertical axes.

Conclusion

This study is the first to investigate the influence of experimental shoulder pain on the rotator cuff as well as scapulothoracic muscle activity with mfMRI. This study demonstrates that acute experimental shoulder pain has an inhibitory effect on the activity of the IS (reduction in T2 shift) during elevation of the arm. Acute experimental shoulder pain did not seem to influence the scapulothoracic muscle activity significantly during elevation of the arm.

Disclaimer

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

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