Muscle Activity Before and After Subacromial Injection

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Context: Shoulder muscle activation in patients with subacromial impingement is highly cited and variable in the literature. Differences between studies could be due to artifacts introduced by normalization practices in the presence of pain. Ultimately, this lack of knowledge pertaining to pathogenesis limits the clinical treatment and restoration of muscular function. **Design**: A total of 21 patients with stage 2 subacromial impingement and 21 matched controls were recruited for EMG testing of their affected shoulder during an arm elevation task. The patients were tested before and after receiving an injection to their subacromial bursa. **Methods**: The EMG from 7 shoulder muscles were measured before and after treatment during humeral motion in the scapular plane. **Results**: Our findings indicate an increase in anterior deltoid, middle deltoid, and upper trapezius activity following the injection; further, this trend extended to the controls. The control subjects had a greater activation of the latissimus dorsi at peak arm elevation when compared with the patient group postinjection. **Conclusions**: Our results indicate that a reduction in subacromial pain is associated with changes in shoulder muscle recruitment, primarily of the deltoid. This change in deltoid activity may lend evidence to rotator cuff function in patients without rotator cuff tears.

Keywords: subacromial impingement, shoulder muscle recruitment, EMG, anesthetic injection

Intraneuronal inhibition secondary to chronic pain may cause reductions in muscle activity.[1] These mechanisms appear to decrease the activity of agonist muscles while simultaneously increasing antagonistic muscle activity, thus reducing the movement and/or velocity in the painful muscle.[1] This suggests that peripheral pain, which overrides and slows motor movements, could be protecting the painful muscle or joint from further injury. However, for the shoulder, a reduction in key muscle activity could result in further injury due to the delicate balance of synergists, including rotator cuff musculature (agonists), which helps to maintain the subacromial space and glenohumeral mechanics during arm elevation.[2] Induced subacromial pain through hypertonic saline injections has been shown to reduce rotator cuff muscle activation and strength, indicating a reduction in humeral centering during arm movements.[3] However, these findings may not be representative of clinical pain, as symptoms were acute and probably do not cause the same adaptations seen in chronic shoulder injury. In patients with subacromial impingement syndrome, previous authors have indicated that peripheral pain may decrease agonist muscle activity, such as the rotator cuff during elevation of the arm.[4] Patients with subacromial impingement have reduced rotator cuff strength and isokinetic performance.[5] However, others report that patients with impingement could have greater rotator cuff activation when compared with healthy controls,[6,7] which may place the rotator cuff at greater risk for being injured as a result of the vicious cycle theory, which is contrary to the pain adaptation model previously described.[8]

Maintaining glenohumeral centering during arm elevation is essential for healthy rotator cuff function. San Juan et al[3] applied a suprascapular nerve block in 20 healthy shoulders and found superior displacement of the humerus under fluoroscopy during arm elevation. This finding further supports the role of the rotator cuff during arm elevation in centering the arm to the opposing forces of the deltoid. Thus, due to the importance of specific agonist muscle activity for maintaining shoulder health, neuromotor adaptations to pain may not be as simple as agonists being reduced and antagonists being increased, as earlier pain adaptation models have predicted. Maintaining rotator cuff and scapular stabilizing musculature may be essential for maintaining overall shoulder health, but in doing so, further degeneration of the rotator cuff may ensue.[7] If rotator cuff activation is unaffected by pain, it would oppose earlier pain adaptation hypotheses, which suggests a decrease in agonist activation in the presence of pain.[1]

Suprascapular nerve block and cadaveric studies have shown that the deltoid muscles must compensate during elevation of the arm when the supraspinatus is inhibited (nerve block) or torn (cadaveric).[3,9,10] This finding provides evidence that the deltoid can be used as a proxy for difficult-to-measure rotator cuff activation,[11] where greater deltoid activity may indicate reductions in rotator cuff activation.[3,9,10] Furthermore, de Witte et al[12] used deltoid activation as an indicator for rotator cuff function in patients with rotator cuff tears. However, there is disagreement in the literature pertaining to deltoid muscle activity in patients with impingement, where several studies suggest that patients have less deltoid activity during arm elevation than controls,[7,13,14] as opposed to data that suggest an increase in deltoid activity for these comparisons.[4] We previously demonstrated that differences between studies could be methodological, where EMG activity is influenced by normalization to a maximal voluntary isometric contraction (MVIC) in the presence of pain.[15] To date, no study has measured deltoid activity in patients with impingement using normalization to a pain-free condition; thus, studies examining deltoid activity in this population are likely overestimating the muscle activity in this population, as the pained condition lowers the maximum capabilities of the deltoid, resulting in a larger percentage of maximum activations during elevation tasks.[15]

In addition to arm abductors, scapular stabilizers, such as the serratus anterior and the trapezius muscle, may have altered activity in patients with subacromial impingement. The serratus anterior and the lower trapezius have been reported to have less activity in

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painful shoulders[6,16–19]; however, some studies have reported no significant differences in activity when compared with healthy controls.[20,21] Interestingly, experimentally induced pain resulted in heightened lower trapezius and activation of the serratus anterior,[22] while larger muscles, such as the upper trapezius[17,18] and the latissimus dorsi,[6,23] appear to be compensating with more activity in painful shoulders versus healthy controls.

Local anesthetic injections to the subacromial space are commonly used to treat shoulder impingement syndrome and have been shown to significantly reduce shoulder pain.[5] Furthermore, these injections have been shown to increase maximal internal and external rotation strength and arm abduction immediately following the injection.[5] This finding suggests that pain may be inhibiting muscles associated with arm abduction and rotation. Farshad et al[24] indicated that, in healthy shoulders, subacromial anesthetic injections have had no influence on deltoid activity or strength, indicating that any changes seen in muscle activity as a result of anesthetic injection observed in impinged patients are likely coming from changes in the sensory system as opposed to the injection having a direct impact on the motor system. To date, we are unaware of studies that have examined shoulder muscle activity during arm elevation in patients with subacromial impingement before and after injection of a local anesthetic. We hypothesize that a local anesthetic injection will result in increased activity of the deltoid, decreased activity of the upper trapezius and the latissimus dorsi, and increased activity of the serratus anterior and the lower trapezius during elevation of the arm in patients with subacromial impingement syndrome.

Methods

An a priori power analysis was conducted based on effect sizes reported in the literature with respect to deltoid electromyography activity.[25] Twenty-one patients (13 males and 8 females) with impingement syndrome and 21 healthy control subjects were recruited for this study. The mean (SD) demographic data for the patients were age 55.6 (8.3) years, height 174.1 (7.9) cm, and weight 78.6 (13.4) kg. The mean (SD) demographic data for the control participants, which were matched within 5 years of age to a patient of the same gender and arm dominance (19 right-handed individuals) were age 54.4 (8.9) years, height 172.9 (9.4) cm, and weight 77.8 (15.1) kg. For the patient population, our inclusion criterion required a positive sign for at least 3 of the following 5 tests: Hawkins–Kennedy, Neer, painful arc, empty can (Jobe), and/or painful external rotation resistance.[26] Patients having had shoulder surgery on the symptomatic side, a positive Spurling test, traumatic shoulder dislocation or instability in the past 3 months, reproduction of shoulder pain with active or passive cervical range of motion, or signs of a rotator cuff tear (drop-arm test, lag signs, gross external rotation weakness assessed by a manual muscle test, or positive image findings) were excluded from this study. Radiographs were taken for all patients, and patients were excluded if the result of their image test indicated a rotator cuff tear, calcific bursitis, or any other pathology inconsistent with stage 2 subacromial impingement. All participation in the study occurred on the same day as their clinical diagnosis. The experimental protocol was approved by the University of Oregon institutional review board of the last author (A.K.). Written and verbal instructions of the testing procedures were provided, and written consent was obtained from each subject.

All EMG activity was normalized to a postinjection MVIC.[15] The MVIC for each muscle was performed postinjection during a 5-second contraction, where the amplitude of the contraction was determined by the root mean squared (RMS) data over the peak activation during the middle 2 seconds of the muscle contraction. Each muscle's MVIC was determined in a unique testing position, with approximately 20 seconds of rest between testing of different muscles.

In addition to MVIC testing, EMG activity was measured during an arm elevation task where patients were asked to complete 3 arm elevation trials. Each elevation trial consisted of the patient raising their affected arm in the scapular plane (30° from the frontal plane) and returning along the same path to a count of 4 in each direction. Real-time feedback of the scapular plane was observed for each arm elevation trial. The trials were repeated when a patient's arm elevation deviated from the scapular plane. All EMG data were filtered between 10 and 1000 Hz before being passed through the analog-to-digital board.

Protocol

For the MVIC collection, each muscle was tested in a unique position using methods previously described. For the anterior deltoid, the patient performing resisted arm flexion with their affected arm placed in 90° of humeral flexion, the elbow flexed at 90°, and the forearm vertical.[27] For the middle deltoid, the patient performed resisted abduction with the affected arm in 90° of shoulder abduction, the elbow flexed at 90°, and the forearm parallel to the floor.[28] Testing for the posterior deltoid involved resisted horizontal extension of the affected arm in 90° of humeral abduction, elbow flexion of 90°, and the forearm parallel to the floor.[28] For the upper trapezius, the patient resisted abduction with the arm placed in 90° of shoulder abduction, the elbow flexed at 90°, and the forearm parallel to the floor.[28] For the lower trapezius, the patient's arm was placed in 90° of humeral elevation in the scapular plane, and the elbow was fixed at 90°. From this position, the subject depressed and downwardly rotated the scapula against resistance.[29] During testing of the serratus anterior, many patients had trouble abducting their arm to 125° in the scapular plane. Therefore, when testing the serratus anterior, the protocol was slightly modified from what was described in the literature.[30] For the serratus anterior, the patient's arm was abducted 90° in the plane of the scapula, and the patient performed resisted elevation with force applied to the humerus in the direction of adduction toward the lateral boarder of the scapula.[30] The latissimus dorsi was tested with the subject performing maximal shoulder adduction against resistance with the humerus abducted 30° (in the frontal plane) and internally rotated.[31]

The Fastrak magnetic tracking device (Polhemus, Colchester, VT) was used for collecting 3D humeral and thoracic motion within the treatment room of patients receiving an anesthetic injection. The Polhemus unit consists of a transmitter, 3 receivers, and a digitizer, all wired to a system electronics unit, which determines the relative orientation and position of the sensors in space. The transmitter serves as a global reference frame and was fixed to a rigid plastic base and oriented such that its coordinate axes aligned with the cardinal planes of the human body. The digitizer sensor was used to identify anatomical landmarks with respect to the global reference frame. After digitization, the arbitrary coordinate systems defined by the Polhemus were converted to anatomically appropriate coordinate systems based on the recommendations of the International Society of Biomechanics Committee for Standardization and Terminology.

Experimental Procedure

Once the digitization and calibration were completed, the participants completed 3 arm elevation trials. Kinematic and EMG data

were synchronized and collected continuously at a rate of 40 and 1200 Hz, respectively, and then averaged for data analysis. The patients were asked to give their current shoulder pain level on an analog pain scale immediately after completing the shoulder elevation task.

Following the kinematic and EMG collection, the patients received a landmark-guided subacromial injection of anesthetic (6 cc 0.5% bupivacaine with epinephrine and 3 cc lidocaine with epinephrine) and corticosteroid (1 cc 40 mg methylprednisolone acetate) as part of their normal treatment. The procedure was completed by one of our coauthors (M.S.), who is an orthopedic surgeon. The patients were then given a 15-minute adjustment period and were asked to move their arm in order to disperse the drug within the subacromial bursa. Following the adjustment period, the patients were asked to repeat their arm elevation task following the same procedure as before, and the shoulder pain levels were once again assessed, where patients were blinded from their previous analog pain scale rating. No sensors were removed during the injection, and the same calibration data were used when measuring kinematics postinjection.

Statistical Analysis

To determine the differences in pain following treatment, paired *t* tests were used between the preinjection and postinjection Visual Analog Scale (VAS) pain scores. To determine the influence of treatment on muscular activity, seven 2-way repeated-measures analysis of variance were used. Each muscle activation (%MVIC) for the anterior, middle, posterior deltoid, latissimus dorsi, upper and lower trapezius, and serratus anterior were treated as unique dependent variables. The humeral elevation angle at 4 increments, 30°, 60°, 90°, and 120° were treated as the first independent variable, and the conditions (preinjection and postinjection) were treated as the second independent variable. For significant interactions, pairwise comparisons were performed using the least significant difference test. To compare the effect of treatment with respect to healthy controls, seven 2-way mixed-effects analysis of variance were used. The humeral elevation angle at 4 increments was treated as the repeated-measures independent variable, and group (postinjection impingement vs controls) was treated as the between-subjects factor. For significant interactions, pairwise comparisons were performed using the least significant difference.

Results

All patients complained of pain during the clinical examination and during elevation of the arm. Following the subacromial injection, all patients reported a modest decrease in pain. A dependent-samples *t* test indicated a significant reduction in the VAS pain scores before (54.3 [27.6]) and after (19.3 [14.8]) treatment ($P < .001$, effect size of 1.46), where patients had an average reduction in pain of 65%, which marked a 35 (22.4)-point difference on the VAS chart (CI, 25.2 to 44.8). Our changes in VAS are consistent with the mean changes reported in the literature for this treatment and approach.[5]

Anterior Deltoid

No significant interaction was found between treatment and the humeral elevation angle for the anterior deltoid ($P = .209$). Significant effects of treatment were found at all levels of elevation, and a significant effect of humeral elevation was detected where, on average, the preinjection state of the deltoid required 31.5% of maximal activation during elevation, and the postinjection state of the deltoid required 34.5% of maximal activation ($P = .017$ and $P = .001$, respectively). Comparing postinjection anterior deltoid activation for patients with impingement syndrome versus healthy controls, a significant interaction between the humeral elevation angle and group (controls vs impingement population) was detected ($P = .008$). Post hoc pairwise comparisons indicate that significant differences were pronounced between groups at 90° of humeral elevation ($P = .019$), where the impingement syndrome group required, on average, 11% greater anterior deltoid activation than the controls (Figure 1). The effect sizes and 95% CI for the mean difference postinjection–preinjection for the anterior deltoid was 0.34 (−0.8 to 6.8), respectively.

Middle Deltoid

A significant interaction was found between treatment and the humeral elevation angle for the middle deltoid ($P = .023$). Post hoc pairwise comparisons indicate that no significant differences occurred at 30° of elevation ($P = .488$); however, following treatment, the patients required, on average, 3.5% greater activation of the middle deltoid at 60° ($P = .043$), 4.9% greater activation at 90° ($P = .05$), and 7.3% greater activation at 120° ($P = .014$) of arm elevation. Comparing postinjection activation of the middle deltoid for patients with impingement syndrome versus healthy controls, a significant interaction between the humeral elevation angle and group (controls vs impingement syndrome population) was detected ($P = .031$). Post hoc pairwise comparisons indicate that significant differences were pronounced between groups at 60° and 90° of humeral elevation ($P = .05$, $P = .006$ respectively), where the impingement syndrome group required, on average, 7.6% greater activation of the middle deltoid at 60° and 14.4% greater activation at 90° of arm elevation (Figure 2). The effect sizes and 95% CI for the mean difference postinjection–preinjection for the middle deltoid was 0.38 (0.5 to 7.9), respectively.

Posterior Deltoid

No significant interactions were found between treatment and humeral elevation angle for the posterior deltoid ($P = .107$). No significant effect of treatment was found ($P = .052$); however, a
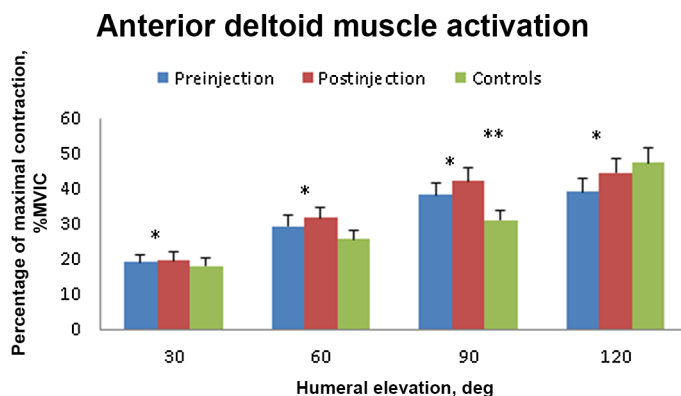
Anterior deltoid muscle activation

Figure 1 — Activation of the anterior deltoid during arm elevation pre (blue/left) and post (red/middle) anesthetic injection versus healthy controls (green/right). %MVIC indicates percentage of maximal voluntary isometric contraction. *Significant differences for within-subject comparisons. **Significant differences for between-subject comparisons.
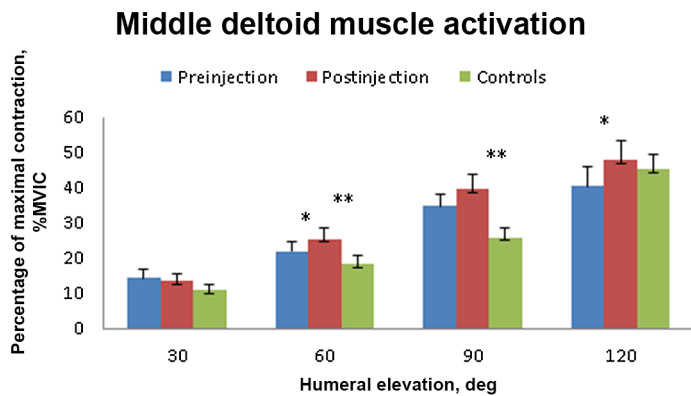
Middle deltoid muscle activation

Figure 2 — Activation of the middle deltoid during arm elevation pre (blue/left) and post (red/middle) anesthetic injection versus healthy controls (green/right). %MVIC indicates percentage of maximal voluntary isometric contraction. *Significant differences for within-subject comparisons. **Significant differences for between-subject comparisons.
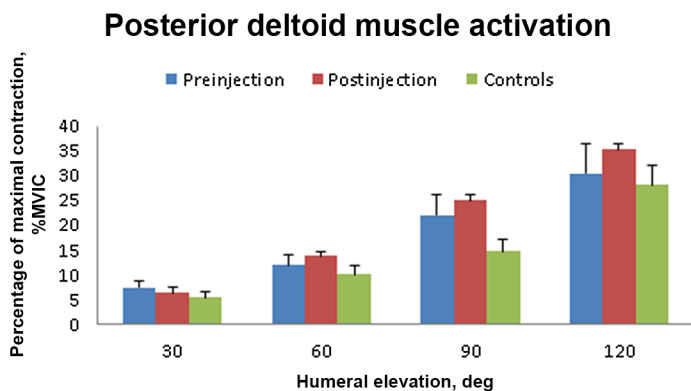
Posterior deltoid muscle activation

Figure 3 — Activation of the posterior deltoid during arm elevation pre (blue/left) and post (red/middle) anesthetic injection versus healthy controls (green/right). %MVIC indicates percentage of maximal voluntary isometric contraction.

significant effect of angle was found ($P = .001$). No significant interactions ($P = .246$) or significant effects of group ($P = .214$) were detected between patients with impingement syndrome and healthy controls (Figure 3). The effect sizes and 95% CI for the mean difference postinjection–preinjection for the posterior deltoid was 0.26 (1.4 to 5.7), respectively.

Latissimus Dorsi

No significant interactions were found between treatment and humeral elevation angle for the latissimus dorsi ($P = .980$). No significant effect of treatment was found ($P = .091$); however, a significant effect of angle was found ($P = .001$). Comparing the postinjection activation of the latissimus dorsi for patients with impingement syndrome versus healthy controls, a significant interaction between the humeral elevation angle and group (controls vs impingement population) was detected ($P = .028$). Post hoc pairwise comparisons indicate that significant differences were only pronounced between groups at 120° of humeral elevation ($P = .041$), where the control group required on average 13.0% greater activation of the latissimus dorsi at 120° than the impingement

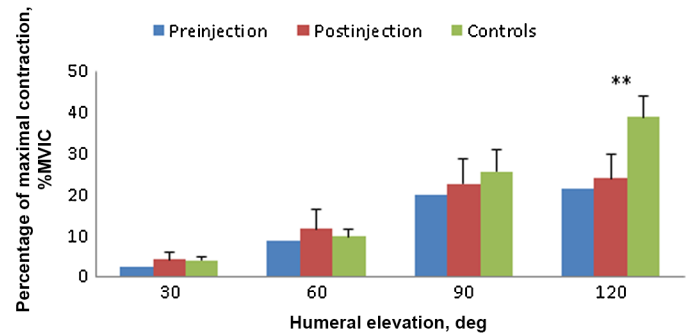## Latissimus dorsi muscle activation

Figure 4 — Activation of the latissimus dorsi during arm elevation pre (blue/left) and post (red/middle) anesthetic injection versus healthy controls (green/right). %MVIC indicates percentage of maximal voluntary isometric contraction. **Significant differences for between-subject comparisons.

group postinjection (Figure 4). The effect sizes and 95% CI for the mean difference postinjection–preinjection for the latissimus dorsi was 0.24 (1.9 to 6.9), respectively.

Upper Trapezius

A significant interaction was found between treatment and humeral elevation angle for the upper trapezius ($P = .005$). The post hoc pairwise comparisons indicate that no significant differences occurred below 120° of elevation; however, following treatment, the patients required, on average, 14.5% greater activation of the upper trapezius at 120° of arm elevation. Comparing the postinjection activation of the upper trapezius for patients with impingement syndrome versus healthy controls, a significant interaction between the humeral elevation angle and group (controls vs impingement population) was detected ($P = .041$). The post hoc pairwise comparisons indicate that significant differences were pronounced between groups at 30°, 60°, and 90°, but not 120° of humeral elevation ($P = .019$, $P = .001$, $P = .001$, $P = .280$, respectively), where the impingement group required, on average, 8.9% greater activation of the upper trapezius at 30°, 15.9% greater activation at 60°, and 19.5% greater activation at 90° of arm elevation (Figure 5). The effect sizes and 95% CI for the mean difference postinjection–preinjection for the upper trapezius was 0.26 (−2.8 to 11.8), respectively.

Lower Trapezius

No significant interactions were found between treatment and humeral elevation angle for the lower trapezius ($P = .651$). No significant effect of treatment was found ($P = .100$); however, a significant effect of angle was found ($P = .001$). When comparing the postinjection activation of the lower trapezius with respect to healthy controls, we detected a violation of sphericity; therefore, for subsequent analysis, Greenhouse–Geisser corrections were used. No significant interactions ($P = .063$) or significant effects of group ($P = .831$) were detected between patients with impingement and healthy controls; however, a significant effect of angle was detected ($P = .001$) (Figure 6). The effect sizes and 95% CI for the mean difference postinjection–preinjection for the lower trapezius was 0.23 (−2.8 to 8.6), respectively.
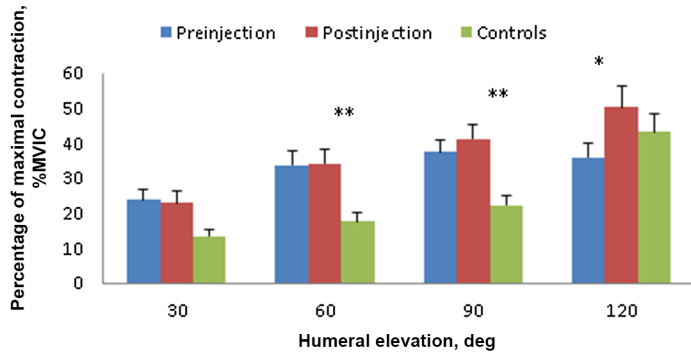
Upper trapezius muscle activation

Figure 5 — Activation of the upper trapezius during arm elevation pre (blue/left) and post (red/middle) anesthetic injection versus healthy controls (green/right). %MVIC indicates percentage of maximal voluntary isometric contraction. *Significant differences for within-subject comparisons. **Significant differences for between-subject comparisons.
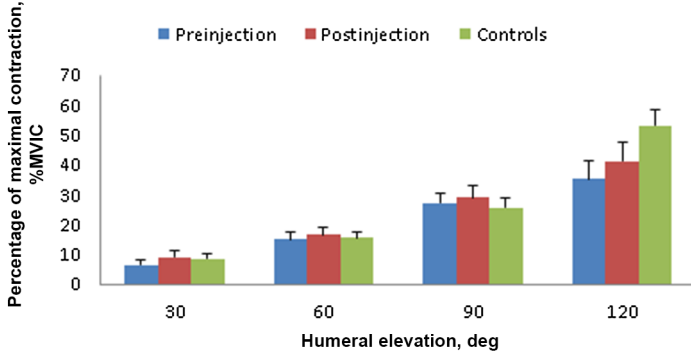
Lower trapezius muscle activation

Figure 6 — Activation of the lower trapezius during arm elevation pre (blue/left) and post (red/middle) anesthetic injection versus healthy controls (green/right). %MVIC indicates percentage of maximal voluntary isometric contraction.

Serratus Anterior

No significant interactions were found between treatment and humeral elevation angle for the serratus anterior ($P = .715$). No significant effect of treatment was found ($P = .143$); however, a significant effect of angle was found ($P = .001$). When comparing the postinjection activation of the serratus anterior to healthy controls, no significant interactions ($P = .278$) or significant effects of group ($P = .713$) were detected between patients with impingement syndrome and healthy controls; however, a significant effect of angle was detected ($P = .001$) (Figure 7). The effect sizes and 95% CI for the mean difference post–preinjection for the serratus anterior was 0.29 (–4.6 to 20.3), respectively.

Discussion

Our study is the first to examine scapular and humeral muscle activations during arm elevation in patients with subacromial impingement before and after an anesthetic injection. We hypothesized that pain reduction in patients with stage 2 subacromial impingement syndrome would result in increased activity of the
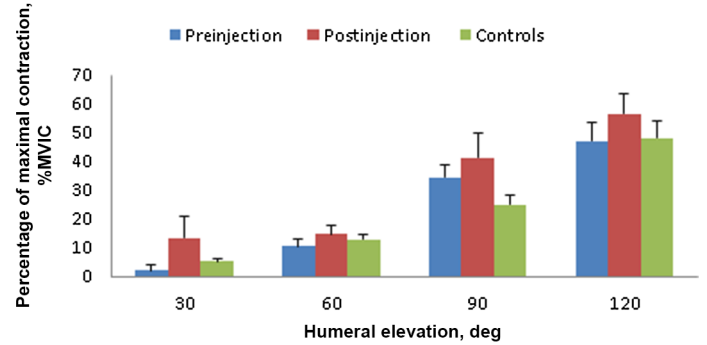
Serratus anterior muscle activation

Figure 7 — Activation of the serratus anterior during arm elevation pre (blue/left) and post (red/middle) anesthetic injection versus healthy controls (green/right). %MVIC indicates percentage of maximal voluntary isometric contraction.

deltoid muscles (all 3 heads, collectively). In addition, we hypothesized that the muscle activations for each superficial shoulder stabilizer muscle postinjection would be indistinguishable from the muscle activations of healthy control subjects. For the deltoid muscles, our hypothesis was partially supported. Following the anesthetic injection and during elevation of the arm, the anterior and middle heads of the deltoid increased. For the anterior deltoid, the magnitude of the activation went from 31.5% activation preinjection to 34.5% activation postinjection for all humeral angles. For the middle deltoid, the increase in activity was observed only at 60°, 90°, and 120° of elevation, where the magnitude of deltoid activity postinjection was greater at higher elevation angles (Figures 1 and 2). In general, our results agree with the literature and indicate that the deltoid may be inhibited by pain.[7,14] Using the deltoid as a proxy for rotator cuff activation,[9,10] our results suggest that, in the presence of pain, rotator cuff activation may be attenuated with respect to controls, which agrees with findings in the literature.[7,13,14] However, contrary to our hypothesis, activation of the anterior and middle deltoid was greater postinjection when compared with healthy controls. This suggests that, following treatment, rotator cuff activity may be further attenuated when compared with healthy controls.[9,10] Mismatches in deltoid and rotator cuff activation may be related to reductions in acromiohumeral distance.[3,4] The posterior deltoid, although not significant, behaved similar to the anterior and middle heads of the deltoid (Figure 3).

In the presence of pain, antagonist muscles generally have heightened activation.[1] Activation of the latissimus dorsi during arm elevation reduces movement velocity and could potentially depress the head of the humerus in patients with impingement; thus, latissimus dorsi functions like an antagonist to the deltoid during elevation of the arm.[23] Cadaveric studies indicate that the latissimus dorsi attaches and covers the inferior angle of the scapula in 43% of cadavers (type 1 scapular connection), which may play a role in limiting scapular anterior tilt, or "scapular winging."[32] We hypothesized that patients preinjection would be compensating with greater activation of the latissimus dorsi than healthy controls and would experience reduced activation following anesthetic injection. However, our results did not support our hypothesis, as we found no influence of injection on activation of the latissimus dorsi during elevation of the arm; however, we did find differences between the impingement group and controls with respect to

latissimus dorsi activation at the apex of humeral motion, where the control subjects required 13% greater activation at 120° of arm elevation (Figure 4). In a study conducted by Diederichsen et al,[22] experimentally induced subacromial pain resulted in increased activation of the latissimus dorsi, which is contrary to our results. Therefore, it is our recommendation that clinicians promote latissimus dorsi activation during rehabilitation to better engage this muscle during arm elevation.

For the upper trapezius, we agree with previous reports, that patients with impingement have greater activation when compared with healthy controls.[17,20] We predicted a decrease in muscle activity following the anesthetic injection; however, our results indicate a 14.5% increase in activation as the arm was elevated to 120° (Figure 5), suggesting that patients may compensate with the upper trapezius despite pain reduction. During rehabilitation, clinicians should seek to reduce upper trapezius involvement during a patient's recovery. Shoulder shrugging may be a compensatory strategy that should be discouraged during arm elevation.

We predicted that patients with impingement would have less activation of the lower trapezius and the serratus anterior when compared with healthy controls and would have increased activation following a local anesthetic injection. Contrary to our hypothesis, patients with impingement did not demonstrate reductions in activation when compared with controls. In addition, we did not observe changes in muscle activation following the subacromial injection (Figures 6 and 7). The lower trapezius and the serratus anterior may have an influence on maintaining the acromiohumeral distance by posteriorly tilting the scapula and aiding the scapula in upward rotation. However, variable findings have been reported for activation of the lower trapezius and the serratus anterior, where some studies have found that patients with painful shoulders have less activation of the lower trapezius[19] and the serratus anterior[17] than in healthy shoulders, whereas others report no differences in activation of the lower trapezius and/or the serratus anterior.[20,21,23] We previously reported that the methodology in previous studies often relies on normalization to an MVIC, which can be influenced by subacromial pain.[15] Furthermore, we have previously found that the lower trapezius was especially sensitive to the normalization method. Therefore, differences between our results and others may be methodological. Despite the lack of differences reported in the present study, we agree with the continued recommendation of promoting the "scapular orientation exercises" used to promote serratus anterior and lower trapezius activity during rehabilitation.[33]

Limitations

We used deltoid function as a proxy for rotator cuff activation; however, indwelling electrodes are the most common method for accessing the rotator cuff's muscular activity directly.[7,13] We opted away from using indwelling electrodes due to the time requirement in instrumentation, where all of our measurements were made in the clinic and needed to be performed in a timely manner. Another limitation in our experiment was that there was no randomization of the treatment protocol and the control group received no treatment.

Conclusions

We demonstrated altered shoulder muscle recruitment before and after pain reduction via an anesthetic injection. Our results suggest that pain influences shoulder muscle recruitment; however, simply reducing pain does not restore muscle recruitment patterns to healthy control levels. In most cases, our results show the opposite,

where the anesthetic injection resulted in further deviation from the healthy control data in patients with impingement. These findings may represent an acute adaptation to a "pain-free" shoulder. Future studies should examine the longitudinal influences of pain reduction on shoulder muscle function.

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