Normalization to Maximal Voluntary Contraction is Influenced by Subacromial Pain

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In this study, we aimed to determine if electromyography (EMG) normalization to maximal voluntary isometric contractions (MVIC) was influenced by subacromial pain in patients with subacromial impingement syndrome. Patients performed MVICs in unique testing positions for each shoulder muscle tested before and after subacromial injection of local anesthetic. In addition to collection of MVIC data, EMG data during an arm elevation task were recorded before and after injection. From a visual analog pain scale, patients had a 64% decrease in pain following the injection. Significant increases in MVICs were noted in 4 of the 7 shoulder muscles tested: anterior, middle and posterior deltoid, and lower trapezius. No significant differences were noticed for the upper trapezius, latissimus dorsi, or serratus anterior. MVIC condition (pre and post injection) had a significant influence on EMG normalization for the anterior deltoid and lower trapezius muscle. Results indicate that subacromial pain can influence shoulder muscle activity, especially for the deltoid muscles and lower trapezius. In addition, normalization to MVIC in the presence of pain can have unpredictable results. Caution should be taken when normalizing EMG data to MVIC in the presence of pain.

Keywords: electromyography, maximal voluntary isometric contraction, normalization, pain, shoulder impingement

Shoulder muscle activation has been measured using electromyography (EMG) since the early 1940s when Inman et al first examined raw EMG signals from shoulder musculature.[1] Since that time, collection and analysis of EMG data has been standardized to make comparisons between individuals and between studies.[2] Recently, normalized EMG was used to examine shoulder muscle activity in healthy subjects, as well as patients with subacromial impingement syndrome.[3–8] Phadke et al[9] composed a comprehensive review of scapular muscular activation during arm elevation in patients with subacromial impingement syndrome versus healthy controls. From that review article, 7 studies used similar methodological protocols which normalized EMG activity of scapular muscles to maximal voluntary contractions (MVIC) for patients with subacromial impingement and healthy controls.[9] From this review, discrepancies are reported between studies in terms of which scapular muscles have greater activation or lesser activation in the patient population versus healthy controls.

Most studies agree that upper trapezius activity is greater in patients with subacromial impingement than in healthy controls.[3,5,10] However, for lower trapezius activity, Ludewig and Cook[5] describe lower trapezius activity to be greater in patients with impingement than in controls; however, Cools et al[7] described lower trapezius activity to be slower to respond for this population. Three studies found no difference in lower trapezius activity in patients with impingement when compared with healthy controls.[6,11,12] The literature offers no consensus for serratus anterior muscle activity for the patient population, where several studies suggest that patients have less activation with impingement[3,5,10] and others have found no

difference in activity for this population versus controls.[6,11,12] Several authors have described the middle deltoid muscle to have less activation in patients with impingement than in healthy controls;[4,13,14] however, Myers et al[15] found the middle deltoid to have greater activity in the patient population than in healthy controls. Differences between studies may be due to the severity of the impingement disorder, where some patients have greater disability due to their pain whereas others do not.[16] Furthermore, patients may be avoiding activation of certain muscles, such as the deltoids due to pain inhibition,[16,17] or employ compensatory strategies to avoid further damage of the supraspinatus tendon within the subacromial space during MVIC testing.[14] Other differences between studies could be related to the normalization of EMG used. Although MVICs are the most commonly practiced normalization tool,[9,55] others have used a weighted condition[5] and reference values.[3]

Experimentally-induced joint pain has been found to attenuate maximal force production in various joints.[18–20] For the shoulder, experimental pain was found to result in a 33% reduction in maximal isometric external rotation force.[19] Further, the reduction in external rotation force was coupled with inhibition of the infraspinatus muscle, which is a synergist.[19] During experimental pain to the neck region, synergist muscles had reduced activation; however, the kinetic output was unchanged.[21] Similarly Arendt-Nielsen et al found that experimental pain during gait altered muscle activity where muscles that were normally silent became more active and ones that were normally active became silent.[22] All of these findings suggest acute muscular adaptations to pain; however, they do not represent chronic adaptations as seen with long-term joint pathology.

To make meaningful EMG comparisons between individuals, standardization of electrode placement and normalization to a MVIC is recommended.[23] Due to the standardization of the EMG normalization, muscle activity is often reported as a percentage of maximal contractibility and not in raw electrical activity as reported by Inman et al.[24] However, it has been cautioned that normalization

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to a MVIC in injured populations may be influenced by pain where maximal voluntary contraction may not be reflective of the full capacity of the muscle being tested.[15,25] If pain inhibits one's ability to maximally contract a muscle as suggested by experimental pain studies,[18–20] the resultant MVIC might bias traditional normalization protocols and result in overestimation of muscle activity in terms of percent of total activation (%MVIC).

Subacromial injections of local anesthetics have been shown to decrease shoulder pain in patients with subacromial impingement[26–28]. Further, subacromial injections have been found to increase force production for the rotator cuff,[29] and increase arm abduction and flexion forces in patients with rotator cuff tears.[17,30] In a study conducted by Brox et al MVICs of several shoulder muscles were shown to be enhanced following a subacromial injection; however, the influence of this change on EMG normalization was not tested.[31] It is the goal of this study to examine the influence of pain on shoulder muscle contractibility as measured by standardized MVIC procedures in patients with subacromial impingement syndrome. We hypothesize that, through the use of an anesthetic subacromial injection, agonist muscles involved in arm elevation (deltoids) will have increased contractibility during MVIC. Further, we hypothesize that normalization to a MVIC in the presence of pain will result in an overestimation of the percent muscle activation during an arm elevation task.

Methods

Subject Recruitment and Selection

Fourteen patients with subacromial impingement participated in this study (55 ± 9 y). Inclusion criterion required a clinical diagnosis of impingement syndrome by one of our authors (MS), and the clinical tests required a positive test of: Hawkins-Kennedy (highest sensitivity), Neer (highest specificity), painful arc, empty can (Jobe), and/or external rotation resistance.[32] Exclusion criteria were: 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 radiographic findings). The experimental protocol was approved by the institutional review board at the University of Oregon. Written and verbal instructions of testing procedures were provided, and written consent was obtained from each patient before testing.

Instrumentation

A Myopac Jr. (Run Technologies, Mission Viejo, CA) system was used to collect differential EMG activity from 7 shoulder muscles (anterior, middle and posterior deltoids, upper and lower trapezius, latissimus dorsi, and serratus anterior). A ground electrode was used on the contralateral clavicle to reduce signal noise. The system had a common mode rejection ratio of at least 90 dB, an amplifier input impedance of 10 MΩ, and a band-pass filter (10–1000 Hz). After the data were sampled at 1200 Hz, it was run through a root mean square (RMS) algorithm with a 50-millisecond window, which served to rectify and low-pass filter the data (rEMG). To calculate the MVIC, each muscle was subjected to a 5-second isometric contraction (described in detail below). The amplitude of the contraction was determined by the RMS data over the middle 2 seconds of the muscle contraction.

Two surface electrodes were used for each muscle tested. Oval, pediatric (32 × 38 mm) ECG electrodes (Ag/AgCl) were selected for study due to their small appearance and low intermuscular cross talk. Electrodes were placed with an interelectrode distance of approximately 40 mm on the bellies of each muscle. Skin was cleaned before electrode placement using isopropyl alcohol preparation pads. Electrode placement for the deltoid muscles,[33,34] upper trapezius,[7,33] lower trapezius,[33,35] serratus anterior,[33,36] and latissimus dorsi[33,37] followed protocols described from the literature.

For collection of 3-dimensional in-vivo kinematics of the shoulder complex during the arm elevation task, the Polhemus Fastrack (Colchester, VT) was used. 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 served 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. For digitization, participants stood with their arm in a neutral relaxed position. Sensors were attached to anatomical segments using double-sided adhesive tape. The first receiver was placed on the thorax on the manubrium of the sternum at approximately the level of T3. The second receiver was positioned on the humerus by mounting it to an orthoplast device positioned on the proximal humerus with elastic straps. The final receiver was positioned over the scapula after mounting it on a custom scapular-tracking device machined from plastic.[38] This tracker was attached to the scapular spine and posterior-lateral acromion with Velcro. The transmitter was then positioned approximately 30 cm behind the subject and was elevated to the height of their scapula using a nonmetallic tripod. Anatomical landmarks were then digitized using the Polhemus stylus, for the thorax T8, xiphoid process, C7, and jugular notch. For the humeral matrix, the medial and lateral epicondyles were digitized and the center of the humeral head was calculated. To calculate the center of the humeral head, the humerus was manipulated in small circular arcs within the midrange of motion of the humerus. The center of the humeral head was defined by the point that moves the least with respect to the scapula through a least squares algorithm during humeral calibration.[38] 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.[39]

Protocol

For the MVIC collection, each muscle was tested in a unique position using methods previously described and reported to generate maximum shoulder muscle activity.[33] Subjects were trained to perform MVICs in each of the following testing positions and were asked to verbally acknowledge competency in each of the following testing positions; the order of muscle testing was not randomized. For the anterior deltoid, the patient performed resisted arm flexion with their affected arm placed in 90° of humeral flexion, the elbow flexed 90°, and the forearm vertical.[33,40] For the middle deltoid, the patient performed resisted abduction with the affected arm in 90° of shoulder abduction, the elbow flexed 90°, and the forearm parallel to the floor.[33,41] 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.[41] For the upper trapezius, the patient resisted abduction with the arm placed in 90° of shoulder abduction, the elbow flexed 90°,

and the forearm parallel to the floor.[41] For the lower trapezius, the patient's arm was placed in 90° of humeral elevation in the scapular plane and the elbow fixed at 90°. From this position, the subject depressed (downward and laterally rotated) their scapula against resistance.[33,42] For generating the greatest amount of activity from the serratus anterior, we faced many challenges due to pain and subsequent risk of patient dropout. We therefore were unable to follow the recommendations from Ekstrom et al.[36] Nor were we able to follow the specific recommendations by Boettcher et al.[33] We therefore established a unique testing position combining certain aspects of each protocol where patients tolerated the position and were able to generate the greatest amount of activity. For testing of the serratus anterior, participants abducted their arm to 90° in the plane of the scapula and performed resisted elevation with force applied to the humerus in the direction of adduction toward the lateral boarder of the scapula. 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.[37] All MVIC testing was performed before and after subacromial injection. Verbal encouragement was given during all MVIC testing. A single MVIC test was performed for each muscle in a unique testing position.

Before receiving the anesthetic injection, patients performed 3 arm elevations with their affected arm moving in the scapular plane (30° anterior to the frontal plane) and returning along the same path to a count of 4 in both directions. Real-time feedback of the scapular plane of motion was observed digitally by the investigator. Trials were repeated when the patient's arm elevation deviated by more than 10° from the scapular plane. EMG and kinematic data were synchronized and collected continuously for the 3 elevation trials. Data from the 3 trials were averaged for subsequent data analysis. Patients were additionally asked to give their current shoulder pain level on a 0–100 visual analog pain scale (VAS) immediately following the shoulder elevation MVIC.

Treatment Procedure

Following kinematic and MVIC evaluations, patients received a subacromial injection of anesthetic (6 mL 0.5% bupivacaine with epinephrine and 3 mL lidocaine with epinephrine) and corticosteroid (1 mL 40mg methylprednisolone acetate) as part of their recommended treatment. The procedure was completed by one of our coauthors (MS), who is an orthopedic surgeon. The injection was performed using an anterior approach where the needle was inserted into the subacromial space and the drugs were administered to the subacromial bursa. Patients were then given a 15-minute adjustment period after the injection and were asked to move their arm to disperse the drug within the subacromial bursa. Following the adjustment period, patients were asked to perform a new MVIC for each of the 7 muscles tested using the same protocol as described above. No electrodes or sensors were moved during the injection.

To compare the MVIC normalization method, EMG activity during the arm elevation trial (preinjection) were normalized twice. The first method normalized EMG activity by the MVIC before the anesthetic injection; the second method normalized the same EMG activity to a postinjection MVIC. A resting trial was subtracted from all EMG data.

$$Method\,1 = \frac{rEMG\,muscle - rEMG\,rest\,(pre)}{rEMG\,MVIC\,(pre) - rEMG\,rest\,(pre)} \times 100$$

$$Method\,2 = \frac{rEMG\,muscle - rEMG\,rest\,(post)}{rEMG\,MVIC\,(post) - rEMG\,rest\,(post)} \times 100$$

The rEMG *muscle (pre)* depicts the rectified EMG signal from each muscle during the arm elevation task preinjection. The rEMG *rest (pre)* illustrates the resting rectified EMG data pre injection. The rEMG *rest (post)* demonstrates the resting rectified EMG data post injection. The rEMG *MVIC (pre)* is the MVIC for each muscle pre injection. Finally, the rEMG *MVIC (post)* is the MVIC for each muscle post injection.

To determine the influence of pain on MVIC, dependent samples t tests were run. The MVIC (mV) was the quantitative dependent variable. The independent variable was treatment condition, pre- and postinjection.

To determine the influence of MVIC on normalization technique during an arm elevation task, 7 two-way repeated measure ANOVAs were used. The percent MVICs during an arm elevation task were the quantitative dependent variables. Injection (pre vs. post) was the categorical independent variable, and humeral elevation angle with 3 levels (30°, 60°, 90° of elevation) was the second independent variable. The significance level used was $\alpha = .05$ for all analyses. Post hoc t tests using a Bonferroni correction were used whenever significant interactions or main effects were detected. For all statistical testing, SPSS version 16.0 (IBM, Chicago, IL, USA) was used.

Results

There was a significant reduction in posttreatment VAS pain ($P < .01$), where pretreatment VAS was on average 56.1 ± 26.1. Posttreatment VAS was on average 21.3 ± 14.7. Mean differences in raw EMG data during the MVIC trials prepost injection were analyzed by dependent samples t tests. Results of these tests indicate that larger MVICs were observed for the following muscles postinjection; anterior deltoid (with a mean difference of 0.14 mV and an effect size of 0.31), middle deltoid (with a mean difference of 0.11 mV and an effect size of 0.37), posterior deltoid (with a mean difference of 0.16 mV and an effect size of 0.72), and lower trapezius (with a mean difference of 0.03 mV and an effect size of 0.34), $P < .05$. No significant differences were found for latissimus dorsi, upper trapezius, or serratus anterior, $P > .05$ (Figure 1).

All results from the ANOVA tests are reported in Table 1. For all muscles tested, only the anterior deltoid had a significant interaction between humeral elevation and the normalization condition (Figure 2). Follow up t tests indicated that pre- and postinjection MVIC normalization differences occurred at 60° of humeral elevation. For all other muscles, no significant interactions were found ($P > .05$). For the effects of normalization condition, the anterior deltoid and lower trapezius were the only muscles influenced, which resulted in overestimation of muscle activity ($P < .05$). With the exception of the upper trapezius, there was a significant effect of humeral elevation for all muscles tested ($P < .05$).

Discussion

From the current study, all patients experienced a reduction in subacromial pain due to an anesthetic subacromial injection. On average, patients experienced a 64% decrease in pain. For the anterior, middle, and posterior deltoid, and lower trapezius muscles, we found that subacromial pain significantly reduced MVIC levels (Figure 1). However, the reduction of pain had no significant effect on MVIC testing for latissimus dorsi, upper trapezius, or serratus anterior. Our results indicate that, following a reduction in pain, the anterior
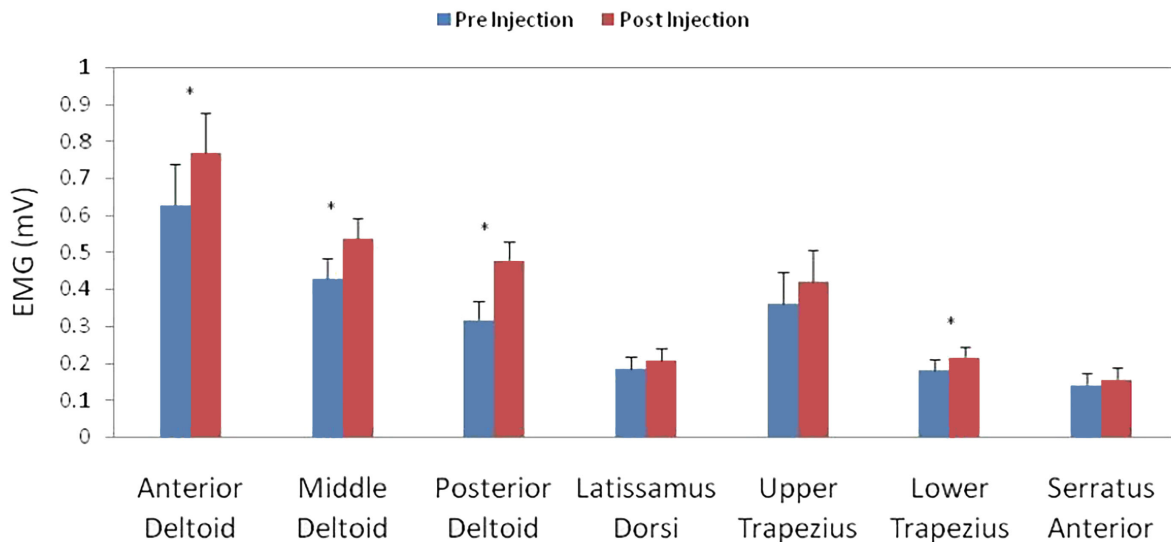
Figure 1 — Pre- and postinjection electromyography (EMG) data (mV) for anterior, middle, and posterior deltoid, latissimus dorsi, upper and lower trapezius, and serratus anterior during maximal voluntary isometric contraction testing. $P < .05$ is indicated by *. Variability is reported as standard errors of the mean.

Table 1 Two-way repeated measures analysis of variance table for the influence of EMG normalization condition on percent muscle activation by humeral elevation angles of 30°, 60°, and 90°

Muscle	ANOVA Factor	df	F-ratio	P-value
Anterior deltoid	Condition (pre—post injection)	1	6.865	.019*
	Humeral elevation angle	2	30.660	.001*
	Condition × elevation	2	3.868	.044*
Middle deltoid	Condition (pre—post injection)	1	0.104	.751
	Humeral elevation angle	2	14.239	.001*
	Condition × elevation	2	0.192	.827
Posterior deltoid	Condition (pre—post injection)	1	3.799	.069
	Humeral elevation angle	2	7.453	.006*
	Condition × elevation	2	1.631	.229
Latissimus dorsi	Condition (pre—post injection)	1	3.094	.102
	Humeral elevation angle	2	7.295	.008*
	Condition × elevation	2	1.051	.380
Upper trapezius	Condition (pre—post injection)	1	2.475	.140
	Humeral elevation angle	2	1.663	.230
	Condition × elevation	2	1.441	.175
Lower trapezius	Condition (pre—post injection)	1	6.486	.024*
	Humeral elevation angle	2	9.380	.004*
	Condition × elevation	2	0.565	.583
Serratus anterior	Condition (pre—post injection)	1	0.557	.469
	Humeral elevation angle	2	14.273	.001*
	Condition × elevation	2	2.120	.163

Abbreviation: EMG = electromyography.

Note. *Statistical significance where $P < .05$.

deltoid MVIC was approximately 23% higher after pain reduction, 25% higher for middle deltoid, 50% higher for posterior deltoid, and 19% higher for lower trapezius (Figure 1). The increase in MVIC postinjection may relate clinically to observed improvements in shoulder range of motion and patient self-reported improvements in shoulder strength postinjection.

Results from our normalization methods indicate that both the anterior deltoid and lower trapezius were significantly influenced
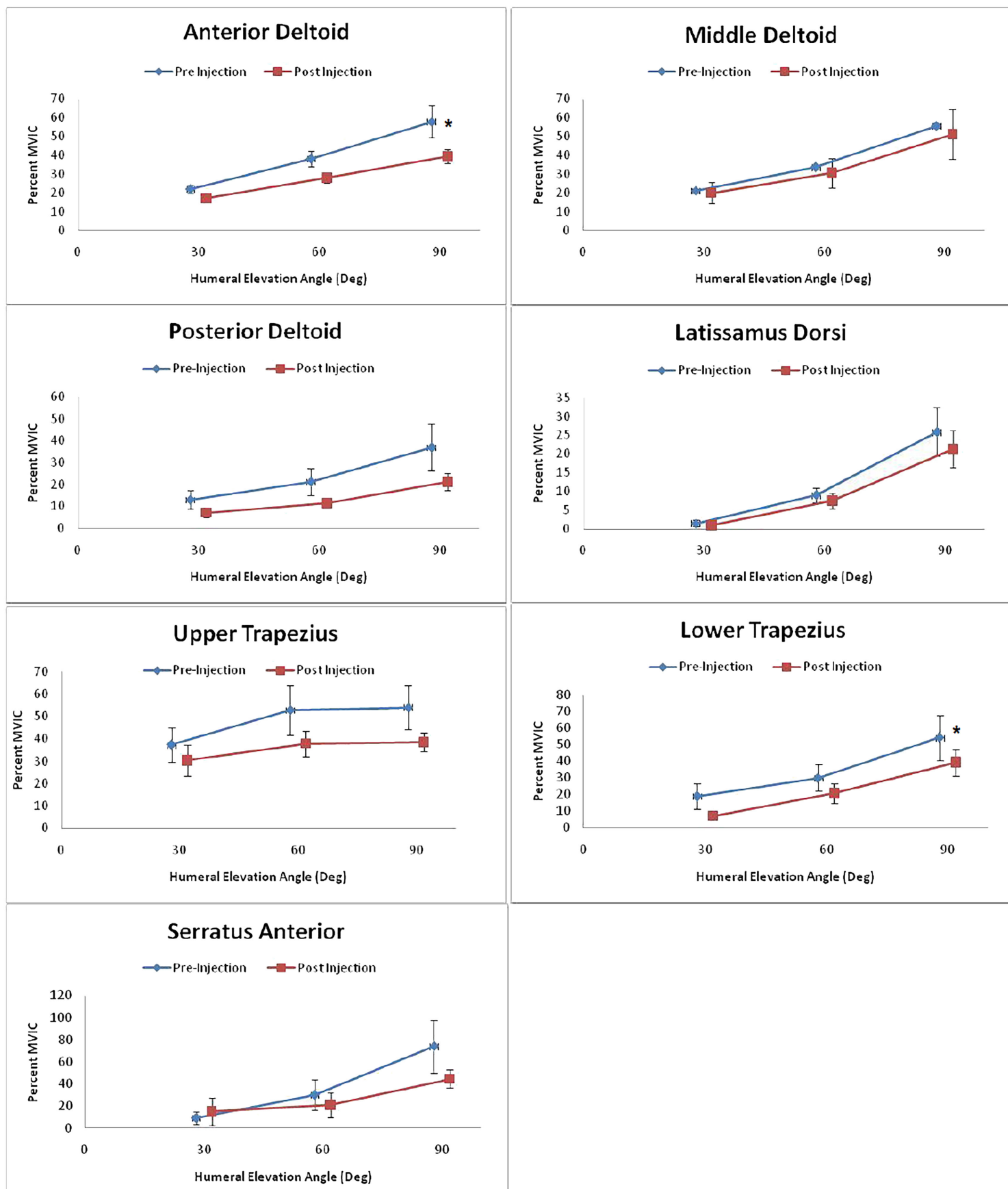
Figure 2 — Pre- and postinjection maximal voluntary isometric contraction normalization during an arm elevation task for anterior, middle and posterior deltoid, latissimus dorsi, upper and lower trapezius and serratus anterior. Variability is reported as standard errors of the mean.

by normalization to an MVIC in the presence of pain. However, for the middle and posterior deltoid, despite having significantly lower muscle activation preinjection during the MVIC testing, there was no significant impact on the normalization of EMG data during an arm elevation task. The unpredictability of the influence of pain on normalization highlights the importance of MVIC testing during a pain-free, or reduced-pain condition.

Submaximal contractions have been attributed to increased pain in patients with subacromial impingement.[6] Painful nociception is associated with decreased muscle activation from agonist muscle groups.[43] This inhibition is believed to be regulated via inhibitory interneurons.[43] We hypothesize that following a subacromial injection, muscles involved in arm elevation (agonists) would have increased contractibility during MVIC. Our results indicated that all 3 deltoid muscles (agonists) had greater MVICs post injection, thus supporting our hypothesis. Furthermore, we hypothesized that normalization to a MVIC in the presence of pain would result in an overestimation of the percent muscle activation during an arm elevation task. Our results indicated that only anterior deltoid and lower trapezius were significantly influenced by the normalization method (pre- versus postinjection MVIC). Therefore, our second hypothesis is only partially supported.

Pain is known to alter muscle activation and human movement.[19,22,44,45] Several adaptations of pained muscle have been described in the literature, where active muscle is inhibited in the presence of pain;[43,46] this can further be extended to active muscle synergists as well.[21] However, other evidence suggests that postural and stabilizer muscles experience increased gain during pain exposure.[45,47] Both muscle adaptation to pain models have evolutionary and physiologic explanations, where a reduction of agonist muscle activation in the presence of pain could serve to reduce movement velocity and thus protect the painful part from further damage.[43] Alternatively, postural and stabilizer muscle gain might increase in the presence of pain to maintain function.[45] Therefore, it is possible that muscle responses to pain are joint specific and potentially dependent on cost to the organism, where postural stability may be vital to survivability of the organism. In a study conducted by Kofler, muscle activation during experimental fingertip pain coupled with a gripping task was found to alter muscle activity based on necessity to maintain grip.[48] This finding further elucidates that muscle alterations in the presence of pain can be dependent on the task or need of the organism.[48] Scapular stabilizers may be similar to postural support muscles where their function contributes toward maintaining normal shoulder kinematics and are integral for shoulder health and function; these muscles include the serratus anterior,[49,50] trapezius,[51] and latissimus dorsi.[52] However, there is no consensus on the behavior of these muscles in the presence of pain.

Our findings suggest that all 3 deltoid muscles and the lower trapezius were significantly reduced by pain, thus resulting in reduced MVIC during testing, which is consistent with findings from other shoulder impingement studies.[4,29] It is possible that, before the subacromial injection, muscle activation from the deltoids and lower trapezius were inhibited, resulting in decreased activation during the MVIC testing. Ludewig et al found that the upper and lower trapezius had more activation in patients with subacromial impingement versus healthy controls.[5] However, our data indicate that lower trapezius MVIC production is greater following a subacromial injection, suggesting that MVIC for the lower trapezius is influenced by pain. Further, this finding supports the necessity to normalize EMG data without pain. We found no change in upper trapezius activity following a subacromial injection. This finding supports evidence from the literature that the upper trapezius may

be compensating in patients with subacromial impingement and may not be inhibited by subacromial pain.[5] Bandholm et al found that patients with shoulder impingement had significantly greater latissimus dorsi activity than controls, supporting the pain adaptation model described by Lund et al.[6,43] We found that latissimus dorsi MVIC activation is unaffected by a subacromial injection, which did not support our hypothesis, nor did it support findings from other subacromial impingement studies;[6,43] however, this finding may suggest that latissimus dorsi is recruited in the presence of pain to help stabilize the shoulder, similar to what has been reported for back stabilizers.[45] For most of the muscles tested, between-subject postinjection electromyographic variability was reduced, indicating that a reduction in pain may be associated with more consistent muscular behavior between patients.

Our results for preinjection shoulder muscle activity in the scapular plane were consistent with findings from other studies which typically report moderate activity (20–50% MVIC) from shoulder musculature.[5,53] With respect to normalization practices, our results indicate that percent activation (% MVIC) for the anterior deltoid and lower trapezius were significantly overestimated when normalized to the painful MVIC condition (Table 1, Figure 2). This result suggests that previous reports may have overestimated the contribution from these muscles.[3–6] Previous studies present conflicting results in terms of muscular activity of patients with impingement versus healthy controls. In the study, we found that pain may significantly influence percent muscle activity of the lower trapezius and anterior deltoid when normalized to an MVIC. With respect to the lower trapezius, Ludewig and Cook[5] demonstrated that patients with impingement syndrome had significantly greater muscle activation than healthy controls at higher arm elevations; all differences were below 20% MVIC. In contrast, de Morais Faria et al[11] demonstrated that there were no significant differences between patients and controls for the lower trapezius (mean differences were under all under 10% MVIC). For the lower trapezius, the current study found muscle activation to be on average 12% MVIC greater when normalized before the injection compared with a postinjection normalization. These results would account for more than half of the differences in %MVIC reported between studies with conflicting results, highlighting the importance of normalization to MVIC in a pain-free environment for the lower trapezius. Similarly, studies conflict in terms of middle deltoid activation between patients with impingement versus healthy controls. Previous studies report that patients with impingement had significantly less middle deltoid activation than controls at early elevation angles, with differences as high as 19% MVIC.[4,13,14] Myers et al[15] reported that patients with impingement have greater middle deltoid activation than controls, where patients had greater activation as high as 15% MVIC at low arm elevation angles. For the anterior deltoid we found significant differences in the normalization method, where preinjection deltoid activation was on average 11% MVIC greater than postinjection activation. However, we did not find significant differences for middle deltoid activation based on normalization method. Therefore, we cannot conclude that differences reported in the literature for the middle deltoid are due to the normalization method. Although most of the comparative studies between patients with impingement syndrome versus healthy controls focus on the middle deltoid and ignore the anterior head,[4,13–15] results from the current study demonstrate that the anterior deltoid is influenced by pain.

In a study conducted by Myers et al, EMG were normalized by the mean activation of 10 arm elevation trial in patients with subacromial impingement.[15] The author cautioned that normalization to a MVIC might be influenced by the impingement diagnosis.[15]

In a study conducted by Roy et al, EMG data from patients with subacromial impingement were normalized to a reference position which consisted of the mean EMG activity while holding the affected arm at a target location while holding a 1-kg weight.[54] Other methods for EMG normalization for patients with subacromial impingement have been described.[3] Although these studies have taken measures to avoid the influence of pain on the normalization of EMG, the ability to compare and contrast between studies is obstructed by the differences in methodology. From several review articles on muscle activity in patients with impingement syndrome, the most commonly used normalization technique described in the literature is with respect to a MVIC.[9,55] Using similar methodologies for EMG normalization between studies aids researchers and clinicians to reach conclusions.

This study does not address rotator cuff activity in patients with subacromial impingement. It is highly likely that pain has an influence on rotator cuff activity, specifically the supraspinatus, as this muscle is most often affected by subacromial impingement.[4,14,15,56] Indwelling electrodes are the most common method for accessing the rotator cuff muscular activity; however, due to patient and clinician time constraints our instrumentation was limited to surface electromyography. We acknowledge that 4 MVIC normalization tests have been identified as sufficient for producing stable normalization practices in shoulder musculature;[33] however, we were unable to collect more than a single MVIC per muscle due to time limitations of our orthopedic specialists and patient needs. Due to the lack of randomization, which was constrained by our clinical design, it is possible that learning effects and familiarization to the protocols and maximal voluntary testing could impact the results postinjection.

Our study suggests that future researchers take caution when normalizing EMG to maximal activation in the presence of pain, especially in patients with subacromial impingement. In addition, researchers should take advantage of reducing pain in the affected arm before making MVIC measurements whenever possible.

Acknowledgment

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