EMG activity of selected rotator cuff musculature during grade III distraction and posterior glide glenohumeral mobilization: results of a pilot trial comparing painful and non-painful shoulders

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Objectives: The objectives of this pilot study were to investigate rotator cuff activity that may be present during grade III distraction and posterior glide mobilization of the glenohumeral (GH) joint, as well as to examine any differences in response between painful and non-painful shoulders utilizing these techniques.

Methods: EMG data were collected using Delsys EMGworks® software and Trigno® mini-wireless electrodes for the supraspinatus, infraspinatus and upper trapezius musculature during grade III GH distraction and posterior glide mobilization. A total of 20 shoulders (10 painful, 10 non-painful) were recruited from a sample of convenience. Submaximal voluntary dynamic contraction against gravity was used as reference for each of the three selected muscles. Participants underwent two trials of each mobilization, and the mean results for each group were assessed using descriptive statistics (mean, standard deviation) and effect size.

Results: Both the painful and non-painful groups exhibited considerable levels of rotator cuff activity during each test parameter, with the painful group consistently generating higher supraspinatus and infraspinatus RMS and peak force activity. Analysis of the peak combined rotator cuff activity during distraction ($d = 0.58$) and posterior glides ($d = 0.64$) suggests moderate-to-high practical significance of the results.

Discussion: GH distraction and posterior glide mobilizations have traditionally been thought of as passive treatment procedures. The results of this pilot study indicate that the supraspinatus and infraspinatus are significantly active during these techniques. Findings suggest that during these techniques, the total infra/supraspinatus EMG activity approaches the level produced while raising the arm against gravity. **Level of evidence:** 2b

Keywords: Shoulder, Mobilization, Rotator cuff, EMG

Background

It has long been advocated in the literature that therapist-generated accessory mobilization of the glenohumeral (GH) joint is beneficial in helping patients achieve improved range of motion (ROM) and decreased pain in the treatment of either post-surgical¹ or non-surgical pathologies.^{2–5} Joint mobilization techniques are thought to produce various therapeutic effects.⁶ A biomechanical effect may exist when forces are directed towards capsular resistance. The mechanical effect may include breaking up of adhesions,⁷ realigning collagen fibres⁷ or increasing

fibre glide^{7,8} when the capsule is stressed.⁹ Furthermore, mobilization techniques may serve to improve or maintain joint mobility by improving the flow and exchange of synovial fluid.^{7–9} Consequently, gliding of the GH joint is used in the treatment of a variety of pathologies, such as impingement,⁴ adhesive capsulitis^{3,5,10} and in post-operative rehabilitation.¹

The glenohumeral posterior glide and distraction mobilizations have been well researched in regard to their ability to produce tissue deformation and stretch of the glenohumeral joint capsule.^{5,11–13} The posterior glide technique has demonstrated the ability to create significant accessory glenohumeral movement and capsular deformation utilizing Kaltenborn grade III mobilization

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Table 1 Participant demographics

Variable	Control	Painful
Age	25.30 ± 1.90	26.10 ± 4.23
Gender (male n, %/female n, %)	3,30%/7,70%	2,20%/8,80%
Height (inches)	67.90 ± 3.31	64.90 ± 3.45
Weight (pounds)	152.00 ± 23.83	152.10 ± 26.72
NPRS	0.00 ± 0.00	3.10 ± 0.88

forces.^{11,12} Previous work has demonstrated that during posterior translational mobilizations, the posterior rotator cuff serves as a passive restraint resisting as much as 35% of the overall posterior force at 60° abduction in a cadaver model.¹⁴ However, these cadaver studies do not take into account the role of an active rotator cuff contraction as a possible restraint to these therapist-generated mobilizing forces. Hsu et al.¹⁴ also assessed the effect of a Kaltenborn grade III distraction glide in the glenohumeral resting position, resulting in 27.38 mm of displacement in a cadaver model. Gokeler et al.¹⁵ examined distraction *in vivo* with radiographic measurements, and found only 0.3-mm distraction with a 14-kg distraction force, despite patient and therapist perception of adequate relaxation. This discrepancy in results suggests that the shoulder musculature may function as both an active and passive restraint during passive accessory motions. The extent to which the rotator cuff contracts during this process is not clear from the literature at this time.

Evidence does exist regarding the effects of shoulder pain upon contraction of rotator cuff musculature during rehabilitation activities. Ellsworth et al.¹⁶ compared weighted and unweighted pendulum exercises in normal and pathologic shoulders. Their findings suggest that the supraspinatus and infraspinatus are more active during pendulum exercises in participants with shoulder pathology. Murphy et al.¹⁷ further detailed the EMG activity of the rotator cuff in post-operative shoulders, reporting that the majority of “passive” exercises resulted in an increase in supraspinatus and infraspinatus activity beyond baseline. While these data offer insight regarding the activity of the rotator cuff musculature during various rehabilitative exercises in both normal and pathologic shoulders, little is known about the function of the rotator cuff during accessory mobilizations of the glenohumeral joint in painful shoulders.

In the light of the aforementioned uncertainty regarding the influence of active rotator cuff contraction and pain during accessory glenohumeral mobilizations, the current study sought to: (1) increase the understanding of rotator cuff musculature activity that may be present during distraction and posterior glide mobilizations of the glenohumeral joint, and (2) assess differences in rotator cuff contraction during distraction and posterior glide mobilizations between participants with and without shoulder pain.

Methodology

Methodology for this study was approved by the Institutional Review Board at Texas Woman’s University. The study was registered at clinicaltrials.gov, NCT02491489.

Between March 1 and May 31, 2015, a total of 19 participants comprising 20 shoulders were recruited from the local student population, consisting of 10 participants with pain-free shoulders, and 9 participants with painful shoulders. One participant demonstrated bilaterally painful shoulders with different pathologies and qualities of pain. Demographics specific to the participants are located in Table 1. Inclusion criteria for the control group were as follows: healthy individuals without shoulder pain, ages 18–64. For the painful group: participants with current, reproducible shoulder pain (pain at rest, pain with AROM/PROM/OP, pain with manual muscle test (MMT) or positive impingement tests: Neer’s or Hawkins–Kennedy), ages 18–64. All participants were required to be ambulatory and able to transfer onto a standard treatment plinth. In addition, the participants had to be able to tolerate lying supine for a minimum of 15 min. Participants were excluded if they presented with any of the following: recent (within the previous 6 months) shoulder surgery, shoulder replacement on the involved side, any history of shoulder fractures, active cancer or metastatic disease, coagulation disorders, current pregnancy, rheumatoid arthritis, active litigation for current injury, active workman’s compensation for current injury, osteoporosis or allergy to adhesive tape. All participants provided informed consent.

For all participants, the skin overlying the target area was cleaned with alcohol, then standardized electrode placement was performed as described by Criswell.¹⁸ Electrodes were placed on the upper trapezius, supraspinatus and infraspinatus muscle bellies (Fig. 1). All acquired EMG data were recorded using Delsys EMGworks® acquisition software. Data collection utilized three rectangular (25 mm × 12 mm × 7 mm) preamplified Ag Delsys Trigno mini-wireless electrodes at a sampling rate of 1926 samples/s. The fixed parallel bar interelectrode distance on the Delsys Trigno sensor was 1 cm with a signal bandwidth of 20–450 Hz. This interelectrode distance preamplifies the signal at the specified site minimizing movement artefact and decreasing crosstalk by helping to reject signals from distant muscles, thus isolating the signal to the muscle underneath the electrode. The specific bandwidth of our

Figure 1 Electrode placement.

electrodes has been found to be the most appropriate for a clean EMG signal.¹⁹ The sampling rate of 1926 Hz surpassed the minimum of 1346 Hz needed for good representation of the shoulder muscles power spectrum.²⁰ The EMG data were high-pass filtered with a fourth-order zero-lag Butterworth filter at a cut-off of 20 Hz, full wave rectified, and then low-pass filtered at a cut-off of 10 Hz.

Submaximal voluntary dynamic contractions (VDC) against gravity were used as the reference for all participants in this study. A VDC has been reported to be more accurate in estimating lower levels of activity,¹⁸ as well as being more appropriate for symptomatic participants with undiagnosed pathology.²¹ The VDC for each participant consisted of a 15-s hold in a standardized MMT position²² with the middle 5 s used as the reference contraction.

The participants then underwent two trials each of Kaltenborn grade III glenohumeral joint distraction^{3,23,24} and grade I distraction with Kaltenborn grade III²⁴ posterior mobilization^{3,23} performed by two separate investigators. To ensure that data were not affected by various arm positions, a standardized technique maintaining the glenohumeral joint in its resting position of approximately 55° abduction, 30° horizontal adduction and slight external rotation²⁴ was utilized while performing the glenohumeral

mobilizations (Fig. 2). All participants had the same trial order: the first tester applied a 15-s grade III distraction hold²⁴ followed by a 15-s grade I distraction with a grade III posterior glide hold with the middle 5 s of each used as the reference contractions. The second tester then repeated this process. Prior to initiation of data collection, three separate 30-min training sessions were performed approximately 2 weeks apart in order to ensure standard performance of the mobilization techniques. During these sessions, the techniques were practised until all members of the research team agreed that the technique application was consistent between examiners.

EMG Analysis

All EMG data were prepared by a blinded assessor not involved in the data collection process. The middle 5 s of each 15-s hold were selected for analysis, and analyzed using Delsys EMGworks® Analysis software (Delsys, Boston, MA). Root mean squared (RMS) values were obtained for all conditions and visually inspected for movement artifact. After visual inspection, the resulting RMS signals were normalized to the reference contraction, resulting in a %VDC. The mean and peak values during the 5-s time epoch were considered as the variables of interest.

Data Analysis

All data were analyzed using SPSS version 19 Chicago Illinois IBM. All data were analyzed using an intention to treat model, and any missing data points were replaced using imputation via means of the group. This occurred with one control participant whose infraspinatus electrode failed to record any data after the initial 5 s of standardization. Results were assessed for consistency between testers via paired correlations. Once determined that there were no significant differences between testers ($r = 0.871 - 0.997$, $p < 0.001$ for all samples), data from both trials were combined and the resulting means for each condition were used for analysis. Descriptive statistics including means, ranges and standard deviations were assessed for each group condition. The resulting means and standard deviations were used to calculate Cohen's d as an estimate of effect size.

Results

Overall, both groups demonstrated considerable levels of rotator cuff activity during the distraction and posterior glide mobilizations (Table 2). Painful participants generated consistently higher supraspinatus and infraspinatus RMS and peak force activity in comparison to the non-painful group during GH distraction and posterior glide mobilization (Table 3, Figs. 3 and 4). Analysis of the peak combined rotator cuff activity during distraction ($d = 0.58$) and posterior glides ($d = 0.64$) suggests moderate to high practical significance of the results.^{25,26} The upper trapezius did not exhibit significant activity for any

Figure 2 Mobilizations utilized. (A) Longitudinal distraction. (B) Posterior glide.

both the supraspinatus and infraspinatus are moderately active during distraction and posterior mobilizations. There was a moderate effect size indicating that participants with painful shoulders had higher levels of rotator cuff activity compared to those with pain-free shoulders. This is in agreement with previous studies, which found that participants with shoulder pain are less able to relax the rotator cuff musculature during passive ROM activities.^{16,17,28,29} The findings of this study indicate that the combined peak activity of the supraspinatus and infraspinatus approaches the activity required to raise the arm against gravity, particularly in participants with painful shoulders.

It is possible that the choice of mobilization in the resting position influenced the degree of rotator cuff activity observed. Both Debski et al.³⁰, in their study of posterior glide mobilizations, and Hsu et al.¹⁴, in their study of distraction mobilizations, observed greater motion available in the resting position compared to end-range positions of the glenohumeral joint. In the presence of greater degrees of joint laxity, a greater proportion of restraint to translation may fall upon the rotator cuff.³¹ It is not clear from the results of this study if the outcomes would be different with a group of participants with confirmed joint hypomobilities/capsular restrictions. However, this bears consideration as mobilization performed in the loose-packed “resting” position is typically utilized during the early phases of rehabilitation.^{1,23,24,27}

Table 2 Supraspinatus and infraspinatus RMS and peak values across all participants

	Painful	N	Mean	SD	Effect size
Supraspinatus RMS distraction	No	10	26.79	8.21	
	Yes	10	35.60	21.95	$d = 0.53$
Supraspinatus peak distraction	No	10	29.38	8.53	
	Yes	10	39.40	23.91	$d = 0.56$
Infraspinatus RMS distraction	No	10	38.08	24.93	
	Yes	10	51.14	49.06	$d = 0.33$
Infraspinatus peak distraction	No	10	46.05	23.18	
	Yes	10	67.68	72.15	$d = 0.40$
Supraspinatus RMS posterior glide	No	10	26.46	7.41	
	Yes	10	35.47	21.64	$d = 0.56$
Supraspinatus peak posterior glide	No	10	27.84	7.74	
	Yes	10	37.93	22.61	$d = 0.60$
Infraspinatus RMS posterior glide	No	10	36.19	26.07	
	Yes	10	50.74	46.18	$d = 0.39$
Infraspinatus peak posterior glide	No	10	42.56	24.99	
	Yes	10	61.59	56.28	$d = 0.44$

trial conditions regardless of group (range 4.96–7.34% VDC). There were no adverse events reported by participants in either group.

Discussion

Traditionally, it has been assumed that the glenohumeral joint capsule and periarticular connective tissues are the primary targets of mobilization, as the movements are therapist-generated in specific arthrokinematic directions.²⁷ However, the findings of the current study indicate that

The application of translatory joint mobilization has been assumed, in part due to the lack of angular motion, to selectively stress the joint capsule.^{24,27} Clinically, this is in part based on the concept of “end-feel”,³² which has been shown to be a reliable measure of passive movement quality.³³ All mobilizations in the current study were performed to the point of perceived capsular stretch with a “capsular end-feel”. However, the findings bring the actual structural factors into question, as there appears to be a far larger contribution from the posterior rotator cuff musculature

Table 3 Total Supraspinatus + Infraspinatus activity during mobilization

Mobilization	RMS total cuff			Peak total cuff		
	Normal	Painful	Effect size	Normal	Painful	Effect size
Distraction (mean $\pm$ SD)	64.86 $\pm$ 32.22	86.74 $\pm$ 49.07	$d = 0.53$	75.40 $\pm$ 30.04	107.07 $\pm$ 71.07	$d = 0.58$
Range	24.81–139.46	37.76–201.18		28.99–141.74	44.81–294.10	
Posterior glide (mean $\pm$ SD)	62.65 $\pm$ 32.52	86.21 $\pm$ 46.99	$d = 0.58$	70.41 $\pm$ 31.52	99.52 $\pm$ 55.87	$d = 0.64$
Range	25.35–136.01	28.43–184.83		35.13–139.13	36.81–232.47

Figure 3 Distribution of activity during distraction mobilization. **Figure 4** Distribution of activity during posterior glide mobilization.

than previously described. It has long been understood that shoulder stability is the result of a complex interplay between the passive and active stabilizing structures.³⁴ It now appears likely that this mechanism is also active during passive accessory mobilizations, perhaps due to complex sensory-neural and reflexive mechanisms.^{35,36} It has been demonstrated in a feline model that electrically stimulating mechanoreceptors within the capsule cause contraction of the rotator cuff musculature.³⁷ This phenomenon was further demonstrated in human shoulders by Jerosch et al.³⁵, who demonstrated a reflex arc between the shoulder capsule and the rotator cuff musculature in a human model during arthroscopy. These findings led

Diederichsen et al.³⁶ to conclude that sensory inputs can strongly modify muscle activity around the shoulder. This interaction between stretch response and rotator cuff activity may have implications for the use of accessory mobilizations during rehabilitation.³⁶

The current study's methodology may differ somewhat from how mobilizations are applied in the clinical environment. The mobilizations consisted of a 15-s sustained hold in the grade III stretch range. While some authors advocate the use of sustained holds for stiffness,^{24,27} others advocate the use of oscillations with the intention of inhibiting pain and inducing a relaxation effect on the musculature.²³ Normally, the use of oscillations for painful shoulders

would be considered clinically. However, this was not practical for the purposes of this trial as the oscillation would have resulted in excessive movement artefact in the EMG data. It is unknown if oscillatory mobilizations may have resulted in different patterns of rotator cuff activity during the mobilization techniques.

Several potential limitations that must be addressed are inherent across EMG studies, namely electrode type, electrode placement and reference criterion. While a complete discussion of the limitations of EMG analysis is beyond the scope of this manuscript, the interested reader is referred to Farina et al.³⁸ Previous EMG studies of the rotator cuff have utilized fine wire electrodes,^{17,39} surface electrodes¹⁶ or both.⁴⁰ Indwelling electrodes are useful for targeting deeper muscles, but with smaller pickup volumes, they may be inadequate to record data from an entire muscle of interest.⁴⁰ Furthermore, indwelling electrodes create the possibility of causing cramping and pain within the rotator cuff musculature which may confound the reliability of the EMG data.⁴⁰ Inherent limitations of using surface electrodes involve the concept of crosstalk or the unintentional gathering of EMG activity of adjacent muscles rather than a more targeted muscle or specific fibres.⁴⁰ Fortunately, previous studies have demonstrated crosstalk amongst muscles in the rotator cuff using surface electrodes to be minimal,⁴⁰ and the small interbar distance (1 cm) and contact area of the mini Trigno® electrode further reduce the possibility of crosstalk between adjacent muscles due to the confined contact surface area. As different electrode locations over the same muscle have the potential to provide signals with significantly different features,^{38,41,42} standardized placement was utilized with the mini-electrode maximizing the ability to maintain a standardized position over the target muscle.

Differences in reference criteria comprise perhaps the biggest challenge in comparing results from multiple EMG studies. In our review of passive shoulder movements, various authors have defined passive as: less than 20% maximal voluntary contraction (MVC),¹⁶ 20% of VDC needed to raise a 2.25-kg weight,²¹ less than 10% MVC,³⁹ less than 5% MVC²⁸ and baseline resting levels.¹⁷ McCann et al.²¹ consider the VDC to be perhaps the most reliable measure. Unlike maximal voluntary isometric contraction, the VDC is not dependent upon participant effort and is more readily reproducible between participants. The current study indicates values beyond 20% VDC for all mobilization conditions; in other words, the rotator cuff muscles contracted at greater than 20% of the activation required for the participant to raise the arm against gravity in a standard MMT position. However, based on the limitations addressed above, it is unclear how the %VDC relates to the actual forces generated by the rotator cuff, or how the %VDC of the limb compares to conditions of baseline resting, voluntary isometric contraction or additional weight lifted during VDC.

While some extrapolation between the level of EMG activity and the forces applied within the shoulder may be possible, multiple authors remind us that EMG data are not a direct measurement of force produced by the muscles or incurred by the rotator cuff tendons.^{17,21,43,44} Several other factors, beyond per cent activation may contribute to the amount of force generation. These factors include physiologic cross-sectional area, specific tension, length-tension and force-velocity relationships, fibre type and pennation.^{43,44} Therefore, EMG data cannot provide a definitive determination of load during an activity as either “safe” or “not safe”.^{17,21,43} As Hug et al.⁴⁴ stated: “Consequently, estimation of individual muscle force remains one of the main challenges in biomechanics.”

There are additional limitations specific to this study. The participants were a homogenous group consisting primarily of relatively young and healthy individuals. The inclusion criteria were limited to subjective reports of shoulder pain, and while the pain had to be reproducible with ROM, MMT or impingement testing, the majority of participants exhibited subclinical shoulder pathology. Across the sample, all participants presented with relatively low levels of shoulder pain, peaking at a 5/10 on the NPRS. It is not known if higher subjective reports of pain, older participants or specific pathology may provide different results than those found in the current study. However, the results of this study indicate that future study of these research questions is warranted, specifically addressing the limitations noted above.

Conclusions

The current study's findings indicated moderate to high levels of rotator cuff activity across both groups. As a result, the composition of the end feel during glenohumeral mobilizations may need to be reconsidered. It appears likely that the dynamic reinforcement of the capsule by the posterior rotator cuff contributes a larger percentage of the resistance than previously appreciated, particularly in the resting position. Caution is indicated in the early phases of rehabilitation during accessory mobilizations of the glenohumeral joint, since the activity of the supraspinatus and infraspinatus appears to be much higher than previously thought, exceeding the limits of most accepted definitions of passive motion. This effect also appears to be heightened in individuals with shoulder pain.

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