ULTRASOUND IMAGING AS A TOOL WITH WHICH TO ASSESS DIFFERENCES IN SUPRASPINATUS ACTIVATION BETWEEN SYMPTOMATIC AND ASYMPTOMATIC SHOULDERS

by

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A THESIS

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Dr. Andrew Karduna

Measurements of muscle activation are used to assess neuromuscular dysfunction in a wide variety of musculoskeletal pathologies. These measurements typically are conducted using electromyography (EMG), although recent studies have determined that ultrasound imaging is a valid and reliable tool with which to easily perform measurements of muscular activation in a clinical setting. A recent study demonstrated the inter and intra-rater reliability of rehabilitative ultrasound imaging (RUSI) of the supraspinatus in a clinical setting (Temes et al. 2014). The first goal of the present study was to determine whether RUSI is a reliable tool for measurements of muscle thickness of the supraspinatus in patients with unilateral shoulder pain. The second goal of this study was to determine whether there were significant differences in muscle activation as quantified by percent change in muscle thickness between symptomatic and asymptomatic arms of patients. When compared with images analyzed using ImageJ software, this study found RUSI to be a valid method of quantifying supraspinatus width in patients with unilateral shoulder pain. Reliability between raters using ultrasound was also found to be above clinical standards. The results of this study

did not find significant differences in supraspinatus muscle activation between symptomatic and asymptomatic limbs of patients in this study.

These findings suggest that ultrasound imaging can be an accurate tool for quantifying thickness of the supraspinatus in a clinical setting. Our results indicate that further research is necessary to determine whether deficits in supraspinatus muscle activation are present in patients with unilateral shoulder pain, and to determine the contribution of various extrinsic and intrinsic factors to shoulder pathologies.

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Table of Contents

List of Figures

List of Tables

>

Background

The role of muscular activation has been studied in many musculoskeletal pathologies as a way to evaluate functional differences between symptomatic and asymptomatic limbs (Kelly 2005, Lopes 2015). The ability to evaluate deficits in force production of an affected muscle is important both as a diagnostic tool for clinicians and as a parameter to improve patient function. Altered neuromuscular control has been found in patients with shoulder pathologies (Lawrence et.al 2014), and patients with subacromial impingement syndrome have been shown to have decreased ability to maintain submaximal force output (Bandholm et al 2006, Bandholm et al 2008) and decreased force abduction steadiness in concentric contractions (Bandholm et al 2008), amongst other force production alterations (Ludewig & Cook 2000, Lopes 2015). Shoulder pain is second only to low back pain in reported visits to primary care physicians for chronic pain management. (Luimme 2004). Historically, electromyography (EMG) has been utilized as a gold standard technique for evaluating muscular activation in patients with musculoskeletal pathologies, but this technique requires a great deal of training and is not always best suited for use in clinical or rehabilitative settings. Recently, Rehabilitative ultrasound imaging (RUSI) has been shown to be a valid method for measuring muscle thickness in muscles including the lumbar multifidus, (Stokes et. al 2007, Henry et. al 2005**),** lower trapezius (O'Sullivan et. al 2007), middle trapezius (Bentman et. al 2010), lateral abdominal muscles (Teyhen et. al 2007), and supraspinatus (Temes et al 2014). This technique is further validated by the fact that the cross sectional area of a muscle has been shown to be indicative of force production of a given muscle (Esformes 2002).

Introduction

The **cross sectional area** of a muscle has been shown to directly correlate with a muscle's ability to **produce force (**Esformes 2002**)**, which is a parameter that can be quantified by measurements of **muscular activation.** Traditionally, muscle activation of the upper extremity (Reddy 2000, Diederichesen 2009) has been measured using **EMG techniques**, but recent studies have found **rehabilitative ultrasound imaging (RUSI)** to be an accurate tool with which to measure muscle cross sectional area (Esformes 2002, Whittaker 2007, Temes 2014) and muscular activation by comparing measurements of muscle thickness in resting and contracted conditions. This strategy has proven to be effective in quantifying muscular activation in the lumbar multifidus (Kiesel 2007), infraspinatus (Koppenhayer 2015), deep abdominal muscles (Teyhen 2007) and the upper and middle trapezius (O'Sullivan et. al 2007, Bentman et. al 2010). Measurements of cross sectional area of the anterior hip muscles using ultrasound have also been shown to be consistent with MRI obtained images (Mendis 2010), further validating the use of ultrasound as a tool with which to assess muscle size and activation. However, few studies have utilized ultrasound as a tool with which to investigate muscle activation patterns in a patient population with a musculoskeletal pathology.

The **rotator cuff** is comprised of four major muscles: the supraspinatus, infraspinats, teres minor, subscapularis. Together, these muscles stabilize the shoulder and allow the upper extremity to have a large range of motion. Many different pathologies can result in unilateral shoulder pain, one of which is **subacromial impingement syndrome (SIS).** Subacromial impingement syndrome is a shoulder pathology which occurs when the tendons involved in the **rotator cuff** become irritated and inflamed as they pass through the **subacromial space**. The **supraspinatus muscle** is the most commonly involved muscle in impingement syndrome, as well as playing an important role in humeral head stabilization. Shoulder pathologies leading to pain may be due to intrinsic factors such as muscle weakness and **tendinopathy**, or extrinsic factors such as glenohumeral instability and acromioclavicular joint dysfunction (Harrison & Flatow 2011). **Scapular kinematics** have also been thought to play a role in shoulder dysfunction: studies have found patients with impingement syndrome to have abnormal scapular kinematics including **decreased posterior scapular tilt,** anterior tipping and inadequate **upward scapular rotation** as well as decreased range of motion overall, which authors speculate could be due to reducing compromise on the subacromial tissues or compensation for the volume changes of the subacromial space seen in SIS (Lopes et al. 2015, Ludewig & Cook 2000, McClure et al. 2006). Shoulder pathologies such as SIS can be debilitating to those they affect, with 50 percent of those suffering reporting an inability to participate in normal daily activities due to pain (Luime, 2004). In patients such as these, an easy and reliable method for assessing functional differences in muscle is an important aspect of care and rehabilitation. A recent study (Temes et al. 2014) found ultrasound imaging to be a reliable tool with which to measure cross sectional area of the supraspinatus in healthy patients. The present study utilizes ultrasound imaging to examine supraspinatus muscle activation in a patient population suffering from unilateral shoulder pain.

No study has yet attempted to quantify differences in muscular activation through ultrasound measurements of supraspinatus thickness in patients with unilateral shoulder pain. The goals of the present study were to determine whether measurements taken from ultrasound generated images of the supraspinatus in patients with unilateral shoulder pain were accurate when compared to measurements of ultrasound images analyzed with a gold standard image analysis program (ImageJ), and to determine whether there were any differences in muscular activation between symptomatic and asymptomatic limbs of these patients.

Methodology:

Participants:

Participants were 30 subjects (16 men, 14 women) with mean age 56 ± 12 years, mean height 172.2 ± 12 cm, and mean body mass of 81.2 ± 20.4 kg.

Inclusion criteria included:

- unilateral shoulder pain between the neck and elbow
- a score of at least 20 on the Disabilities of the Arm, Shoulder and Hand Questionnaire (DASH)
- decreased range of motion of the shoulder
- a score of at least 2 on a visual analog pain scale.

Exclusion criteria included:

- individuals with a diagnosis of full thickness rotator cuff tear, adhesive capsulitis or cervical radiculopathy
- individuals diagnosed with primary complaint of cervical or thoracic pain and paresthesia and neurological deficit and/or presence of herniated cervical disc
- cervical nerve root pathologies, surgery to the shoulder, cervical or thoracic regions in the previous one year
- pregnancy or osteoporosis
- individuals with evidence of malignancy, bone disease, fracture, dislocation, or acute systemic inflammatory process

- individuals with documented neurological or vascular compromise
- individuals currently receiving treatment by a physical therapist or chiropractor for shoulder pain
- use of cortisone injection in the last 30 days
- individuals who have been in treatment for cancer in the last 6 months.

Subjects were recruited as patients referred for physical therapy to Oregon Medical Group and Therapeutic Associates Inc (TAI) in Eugene and Springfield, OR. All subjects signed informed consent after receiving detailed explanation of the study's procedure. The University of Oregon's Institutional Review Board approved the protocol for the study.

Procedure:

Before testing:

All subjects were tested at TAI's outpatient physical therapy facility by a licensed physical therapist. Before any testing, all subjects completed an intake form detailing medical history, including arm dominance. A licensed physical therapist in the TAI group then screened patients for any neuromuscular or musculoskeletal problems in the cervical spine or upper extremities.

Position:

Subjects were seated in a straight backed chair with arm support. Their arm was placed in a supported position at 45 degrees abduction in the plane of the scapula. This was supported by an arm support which was adjusted depending on patient size, and the angle was measured with a goniometer.

Instrumentation:

Each rater collected three ultrasound images of the supraspinatus in both resting and contracted states on bilateral limbs. A Biosound Esaote (Indianapolis, IN) real time ultrasound unit using a 5MHz curved head and on screen calipers for measurement was used for all data collection. All images were collected in B mode (also known as 2D mode). These images were collected by a second physical therapist present during patient testing. Three total physical therapists were utilized as raters in this study, all of whom had been previously trained with RUSI by both certified ultrasound technicians and a therapist with seven years of clinical RUSI experience. For each patient, two separate therapists from the pool of three certified therapists were utilized, and the order of therapists present for each patient's testing was randomly selected.

Measurements:

Three resting measurements of supraspinatus muscle thickness were taken directly proximal to the spine of the scapula in the middle of the muscle, consistent with where the belly of the supraspinatus is located. This position was found on screen by locating the thickest portion of the muscle medial to the acromion. At this point, the therapist took an image of the patient's resting muscle. This was repeated three times to obtain three images of the patient's resting supraspinatus. After the first therapist completed this procedure, a second therapist repeated the same procedure to obtain three additional images of the patient's resting muscle. The patient then sat in the same position and was asked to hold a 2 lb weight in a static position of 45 degrees abduction in the plane of the scapula, with no arm support. The weight was held for 30 seconds, and repeated three times with one minute of rest between each repetition. Contracted images were taken by the therapist in the same location as the resting images, and ultrasound probe angle was adjusted based on patient's anatomy. Three contracted images were obtained by a first therapist during this procedure, and the patient was subsequently allowed to rest for 5 minutes before the same procedure was repeated by a second therapist and three additional images obtained. The order of testing by the therapists was randomized.

Image Analysis:

A subset of 10 randomly chosen subjects had all images obtained using ultrasound saved and uploaded for analysis using ImageJ software (http://imagej.nih.gov/ij/). ImageJ is a software available from the NIH which has been shown in multiple studies to have very accurate measurements of muscle composition and be in agreement to other similar image analysis software (Fortin 2012, Strandberg 2010). For these reasons it was utilized as a gold standard measurement of muscle thickness in this study. Thickness of the supraspinatus was measured at the widest portion of the muscle between the fascial planes of the supraspinatus. (Figure 1). This measurement was compared to measurements taken using only the ultrasound generated image with no further image analysis, as described in statistical analysis below.

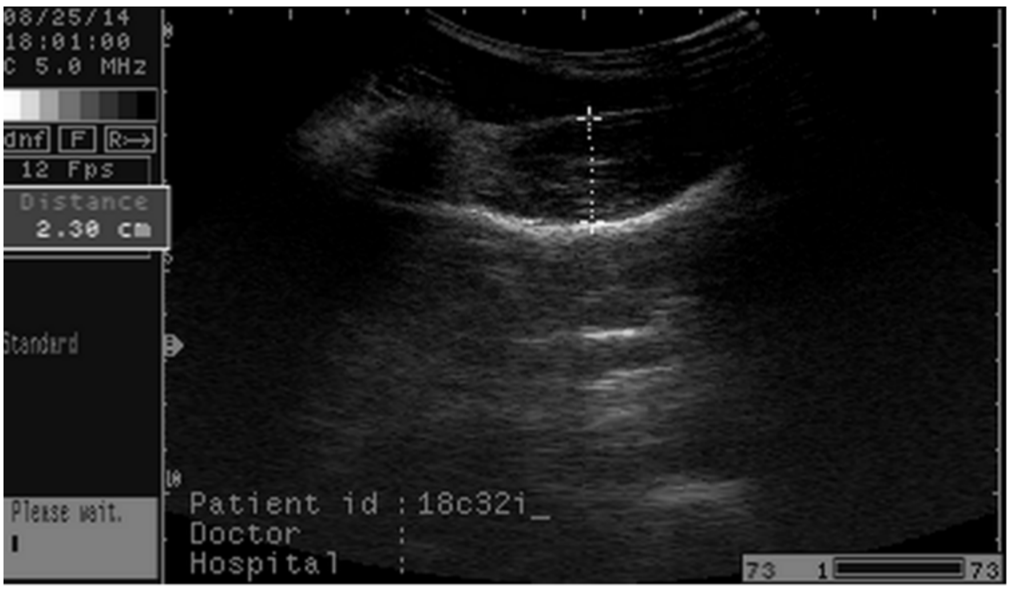


Figure 1: Example of ImageJ analysis of supraspinatus width.

The dotted line indicates the width of the supraspinatus muscle as defined by the individual analyzing the image, as measured between the two fascial planes.

Data Reduction

Statistical Analysis:

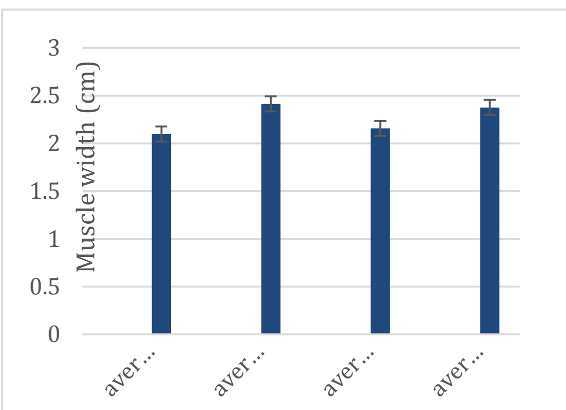
All data were analyzed using SPSS 22.0 Software (IBM, Armonk, NY). Descriptive statistics were presented as mean and standard error of the mean in each condition analyzed. The dependent measure, change in muscle thickness was calculated by the equation: $(\text{thickness}_{\text{contracted}} - \text{thickness}_{\text{rest}}) / (\text{thickness}_{\text{contracted}}) \bullet 100$. In order to compare the percent change in muscle thickness between involved and uninvolved limbs, a paired t test was performed. To determine the validity of the ultrasound measurements in quantifying the width of the supraspinatus, a root mean square (RMS) was calculated of the mean supraspinatus thickness of ImageJ analyzed images and ultrasound only analyzed measurements of supraspinatus thickness. Comparing these RMS values served as a measurement of the average error between the two sets of measurements. To quantify this, a percentage difference in RMS was calculated by the equation:

$(RMS_{\text{ultrasound only}} / RMS_{\text{imasgeJ}}) \bullet 100.$

This analysis was repeated for data from involved and uninvolved limbs. These values are displayed in tables 3 and 4. An intraclass correlation coefficient (ICC) 2,1 model was utilized to assess the intrarater reliability between the raters (Table 2).

Results

Regarding reliability, all ICC values between conditions and between raters were found to be above 0.8 (Table 1). Calculated RMS yielded a mean value of 11% with respect to the uninvolved limb and a mean value of 9.4 % of the involved limb (Table 2, Table 3). The average supraspinatus width in all conditions is shown below in figure 2. The dependent variable measured was percent change in muscle thickness from resting to contracted states. With respect to the dependent variable, there was no significant difference found regarding percent change in muscle thickness from passive to active conditions between involved and uninvolved limbs. ($p=0.201$). The average percent thickness increase of the uninvolved limb was 15.4 %, whereas for the involved limb average percent thickness increase = 12.3 % (Figure 3).



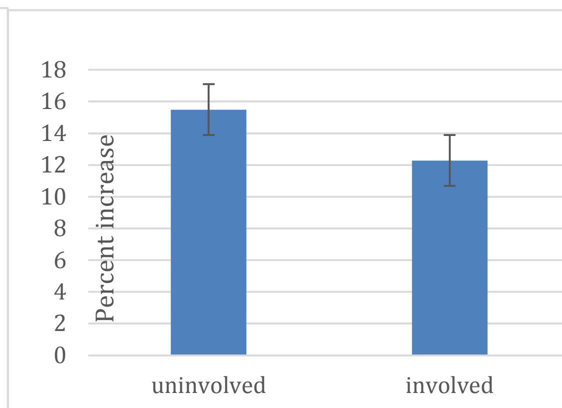


Figure 2: average ± SD supraspinatus width as measured with RUSI

Figure 3: average ± SD percent increase supraspinatus width

Table 1: Average widths and SEM of the supraspinatus

	avg width (cm)	SEM (cm)
Resting uninvolved	2.09	0.07
Contracted uninvolved	2.41	0.06
Resting involved	2.16	0.07
Contracted uninvolved	2.38	0.07

Table 2: ICC Values for active and passive conditions

Involved contracted	Uninvolved contracted	Involved Resting	Uninvolved Resting
0.89	0.89	0.83	0.84

Table 3: Percent difference RMS Involved Side

Protocol	% difference: (RMS/Baseline)
Resting Rater A	9.8
Contracted Rater A	8.9
Resting Rater B	9.5
Contracted Rater B	9.3

Table 4: Percent difference RMS Uninvolved Side

Protocol	% difference: (RMS/Baseline)
Resting Rater A	10.6
Contracted Rater A	10.4
Resting Rater B	13.0
Contracted Rater B	10.0

Discussion

The purpose of the current study was to investigate the validity of rehabilitative ultrasound imaging as a tool with which to measure muscle thickness of the supraspinatus in patients with unilateral shoulder pain, and to investigate any differences in muscular activation of the supraspinatus between symptomatic and asymptomatic limbs of these patients. Thickness measurements of the supraspinatus during passive and active conditions were found to have high validity between ultrasound generated images and images analyzed using ImageJ software (RMS value 11% for symptomatic limb, 9.4% unaffected limb). ICC values were above the threshold of .75 for clinical use when comparing randomly assigned raters, indicating good reliability between raters (Portney at al, 2007). These findings reinforce the recent findings by Temes et. al (2014) showing high inter and intra-rater reliability of RUSI as a tool with which to measure the thickness of the supraspinatus, as well as RUSI studies done on other muscle groups (Stokes et. al 2007, Bentman et al 2010). This is the first study demonstrating validity of RUSI as a tool with which to investigate muscular activation of the supraspinatus in patients with unilateral shoulder pain. The validity of RUSI generated images compared with ImageJ analyzed ultrasound images is promising for future use of this technique in measuring muscle activation, thickness and atrophy in a clinical setting.

This study found no significant difference in supraspinatus muscle activation between symptomatic and asymptomatic limbs ($p=0.201$). Previous studies investigating muscle activation patterns in patients with subacromial impingement syndrome using EMG have yielded varying results. Our results are consistent with those of Michaud et. al (1987), who tested muscle activity using EMG of the supraspinatus and middle deltoid in normal patients and those suffering from SIS and found no significant difference in muscle recruitment of the supraspinatus. Reddy et al (2002) found patients with SIS to have decreased infraspinatus, subscapularis and middle deltoid activity in the 30 to 60 degree arc of motion, but no significant difference in supraspinatus and teres minor, and decreased muscle activity only in the infraspinatus at elevation above 60 degrees. In an EMG study comparing healthy patients and those with unilateral shoulder pain, Deiderichsen et. al (2009) found greater activity of the supraspinatus during abduction compared to normal subjects, which they speculated may have been due to compensating for decreased deltoid activity during the 110 degree elevation task utilized in the study.

The supraspinatus functions as the superior compressive vector in the rotator cuff (Inman et al. 1944**)**, keeping the humeral head from migrating upwards. Superior migration of the humerus decreases the subacromial space, which can lead to pain and pathologies such as SIS. SIS is a common pathology associated with supraspinatus involvement, but is not the only possible cause of unilateral shoulder pain. Any disruption to the normal muscular activity of the supraspinatus can result in humeral head migration, narrowing the subacromial space and either worsening or providing initial cause for a shoulder disorder to develop. Impingement syndrome can also result in compression of the supraspinatus, which has been hypothesized to lead decreased muscular activation as it has been shown to do in previous studies of other muscle groups (Wolf et al 1971, Michaud et. al 1987). It is important to note that the deltoid and supraspinatus act synchronously in the rotator cuff to center the humeral head on the glenoid and prevent humeral migration (Inman et al. 1994, Welker et al. 1994). One limitation of this study was the lack of data collection of deltoid muscle activation, which has been show in previous studies to decrease in patients with unilateral shoulder pain (Lin et. al 2005). A possible explanation for our results is that these patients may have had abnormal muscle activation patterns in muscles other than the supraspinatus (such as the deltoid), resulting in humeral head translation that contributed to narrowing of the subacromial space, and subsequently shoulder pain.

Scapular kinetics have been shown to play a role in impingement syndrome, specifically decreased upward rotation, increased anterior tipping, and decreased external rotation (Ludewig et al 2000, Timmons et. al 2012). These mechanistic differences lead to decreased subacromial space, contributing to SIS. The shape of the acromion has also been shown to play a role in impingement syndrome, with a hooked acromion significantly decreasing subacromial space (Epstein 1993)**.** Either of these explanations could explain the lack of significant activation differences seen in the patient population in our study.

This study only compared muscular activation between symptomatic and asymptomatic limbs of subjects, which could be an additional confounding factor and limitation. In a 2002 study comparing scapular kinematics and motion patterns between the involved and uninvolved limbs of patients with SIS, Hebert et. al found no significant differences in 3D scapular attitudes, but did find that bilateral limbs had scapular rotation magnitudes outside of the range of motion in healthy subjects. During external rotation, Deiderichsen et. al found significant differences in muscle activity on both the symptomatic and asymptomatic limbs of patients with unilateral shoulder pain.

These studies suggest an additional hypothesis that pathogenic differences in bilateral neuromuscular shoulder function and abnormal scapular kinematics precede painful shoulder pathologies. It is plausible that the patient population examined in this study had abnormal muscular activation patterns on bilateral shoulders. An important limitation of this study was the lack of definitive clinical diagnosis for the patient's unilateral shoulder pain. Future studies would benefit from a control patient population, as well as more stringent inclusion criteria regarding the patient's specific etiology of shoulder pain, to control for the myriad of pathologies that can lead to unilateral shoulder pain.

Conclusion

This study found ultrasound imaging to be a valid tool with which to evaluate muscle width of the supraspinatus in patients with unilateral shoulder pain when compared to gold standard image analysis software ImageJ. In addition, the reliability of randomized clinicians utilizing ultrasound imaging was confirmed. This is a promising finding for evaluation of patients with musculoskeletal pathologies, and demonstrates an additional muscle group that ultrasound can be used to evaluate, in addition to the lumbar multifidus, trapezius and lateral abdominal muscles, which have been the focus of previous ultrasound studies (Henry et al 2005, Bentman et al 2010, Van et al 2006). This study did not find evidence to support the hypothesis that patients with unilateral shoulder pain display significantly different muscle activation of the supraspinatus between involved and uninvolved limbs. A variety of intrinsic and extrinsic factors including poor acromial anatomy, altered neuromuscular control, and abnormal scapular kinematics have been noted to contribute to impaired shoulder neuromuscular function. Future studies would benefit from comparing supraspinatus activation in patients with unilateral shoulder pain to a control population. Further research is necessary to determine whether patients with unilateral shoulder pain demonstrate abnormal muscle activation patterns, and to address the contribution of the multiple possible causes of shoulder pathologies.

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