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Technical and measurement report

Thickness of the lower trapezius and serratus anterior using ultrasound imaging during a repeated arm lifting task

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ABSTRACT

The purposes of this study were to establish the reliability for measuring scapular muscle thickness, and to examine how scapular muscle thickness changes with respect to external loads. Participants were asymptomatic subjects recruited from a sample of convenience. Thickness Measures were taken using rehabilitative ultrasound imaging (RUSI) under 11 conditions, rest and 10 progressive loads, for the Lower Trapezius (LT) and Serratus Anterior (SA). The procedures were repeated 1 week later to determine reliability. Bland and Altman limits of agreement and Interclass correlation coefficients (ICC) were used to determine reliability. Separate repeated measure ANOVAs were performed to determine differences in muscle thickness for both muscles across 3 conditions; rest and the 2 loaded conditions that represented the lowest and highest torque values. Results demonstrate good within and between day reliability for the LT (ICC = .86 to .99) and SA (ICC = .88 to .99). For the LT and SA, there were significant differences between the resting thickness and 2 lifting conditions ($p \leq .01$) but not between the two lifting conditions. It was concluded that RUSI is reliable in measuring scapular muscle thickness. RUSI is sensitive enough to detect absolute changes in thickness from resting to a contracted state but unable to detect differences between loads imposed on the shoulder.

1. Introduction

The importance of the peri-scapular stabilizers on both shoulder pain and function has been established by electromyography (EMG) and motion analysis studies (Fayad et al., 2008; Ludewig and Reynolds, 2009; Hardwick and Lang, 2011). As a result, neuromuscular re-education and strengthening are recommended for treating peri-scapular muscle impairments associated with shoulder pathologies (Forthomme et al., 2008; Lucado, 2011). In particular the lower trapezius (LT) and serratus anterior (SA) are often the focus of therapeutic intervention for shoulder pathologies because these muscles control scapular motion in all functional arm movements (Phadke et al., 2009). Prior to initiating interventions, an efficient and accurate assessment is important to identify specific impairments, the impairment magnitude, and establish a baseline to document progression.

Clinical assessment of scapular strength is limited. The SA along with other scapular muscles are difficult to isolate during manual muscle testing (Wadsworth et al., 1987; Hayes et al., 2002; Michener et al., 2005). In the early phases of rehabilitation, a patient's ability to tolerate manual resistance is often limited by pain and post-operative precautions (Deones et al., 1994). In addition, the accuracy of manual muscle testing is limited by tester strength (Deones et al., 1994; Wang et al., 2002).

Rehabilitative ultrasound imaging (RUSI) is a clinical alternative for assessing scapular musculature. RUSI has the ability to detect changes in a specific muscle's architecture without high forces (Kiesel et al., 2007; Mannion et al., 2008; O'Sullivan et al., 2012). RUSI is easy to interpret and noninvasive (Sipila and Suominen, 1996; Miyatani et al., 2000). Because of its ease of set up and interpretation, RUSI may provide a more efficient clinical alternative to quantifying muscle behavior over EMG. RUSI has also been shown to be a reliable and valid objective measure of change in muscle dimensions at rest and during low levels of contractility (Hodges et al., 2003; Hides et al., 2006; Koppenhaver et al., 2009). More specifically, RUSI measures of increased muscle thickness have been shown to be associated with increased torque values, therefore muscle thickness has been described as an indirect measure of isometric strength (Bakke et al., 1992; Freilich et al., 1995; Chi-Fishman et al., 2004).

Measuring LT thickness in a resting prone position has been established as a reliable technique (O'Sullivan et al., 2007; O'Sullivan et al., 2009). However, the results of a recent study

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suggest that resting thickness or change in thickness, measured in prone, may not be sensitive enough to differentiate between patients with shoulder impingement and controls. RUSI's ability to distinguish between those who are pathological and those who are healthy is an important step toward clinical validation. To that end, the authors suggested a measure in a more functional position may yield differing results (O'Sullivan et al., 2012). Assessment of the SA using RUSI has not been previously reported. Thickness of the lower portion of the SA was chosen for evaluation secondary to it's anatomical accessibility (Cuadros et al., 1995) and lower SA activity is thought to play more of a role in shoulder joint stability compared to the upper fibers of the SA (Park and Yoo, 2011).

Before RUSI is used as a clinical assessment tool in the evaluation of either the LT or SA, the responsiveness of RUSI to detect differences in muscles thickness should be investigated. Furthermore, the reliability for measuring thickness at rest and at different loads should be established before RUSIs responsiveness to differences in muscle thickness is determined. Therefore, the first purpose of this study was to establish intra-rater reliability for measuring LT and the lower portion of the SA muscle thickness in a functional position. The second purpose was to determine if an increase in load on the shoulder resulted in an increase in absolute thickness of these muscles.

2. Methods

2.1. Subjects

Seven females (26 ± 4 years) and 7 males (27 ± 4 years) participated in the study. Average body mass index was 22 ± 3 for females and 25 ± 3.2 for males. Subjects were included if able to flex the shoulder above 90° without pain while subjects were excluded if they reported a history of injury or surgery to the upper extremity or spine. The study received ethical clearance from the institution's review board and all subjects read and signed an informed consent statement.

2.2. Subject preparation

Subjects sat on a backless-chair. Female subjects wore a halter top and male subjects were asked to remove their shirts. To control for variations in sitting posture during muscle thickness measurements, each subject was instructed to sit upright (full trunk extension) and slump (full trunk flexion). Maximum extension and flexion were repeated 2 more times, then the subject was asked to rest midway between the 2 motions (Lynch et al., 2010). The subjects were asked to place their forearm on an adjustable table while the shoulder was positioned in 85° elevation and 45° shoulder horizontal abduction from the frontal plane. Positions were confirmed with a standard goniometer. Horizontal abduction was maintained throughout testing by marking arm position on the support.

2.3. Muscular identification

A felt tip mark was placed at the level of the thoracic spine that coincided with the inferior angle of the scapula for ultrasound

Fig. 1. Technique used for measuring shoulder maximum voluntary isometric contraction.

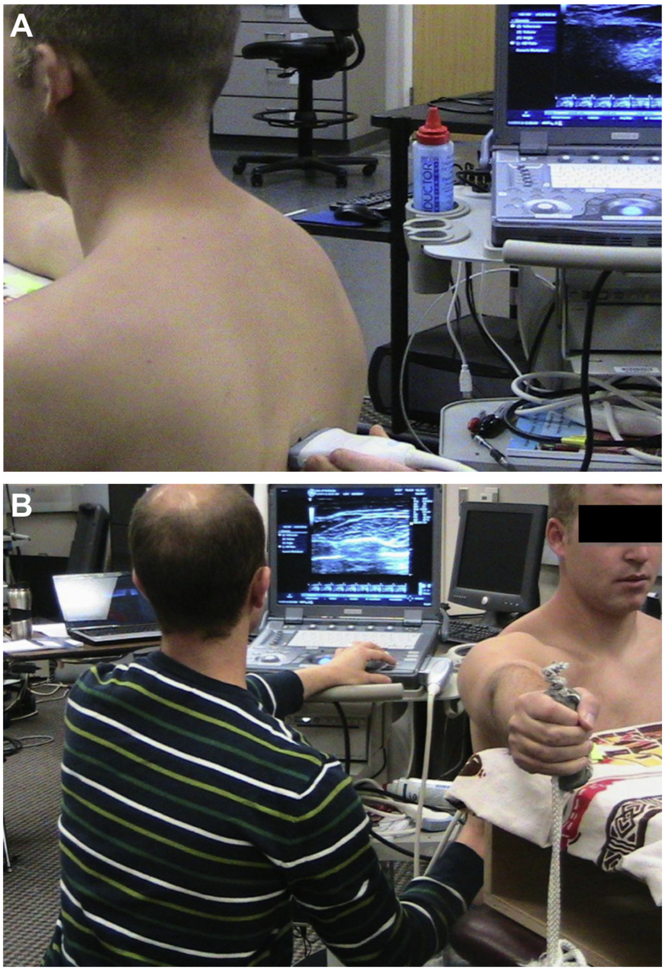

Fig. 2. A. Resting subject position and probe placement for the lower trapezius. B. Subject position during an active lift and probe placement for measuring thickness of the serratus anterior.

transducer placement (O'Sullivan et al., 2007). Good agreement for measuring resting muscle thickness at a similar location has been found with magnetic resonance imaging (O'Sullivan et al., 2009). For the SA, a mark was placed between the pectoralis major and the latissimus dorsi on a rib angle (Basmajian and Blumenstein, 1989; Cuadros et al., 1995). The rib chosen was located at the level of the inferior tip of the scapula.

2.4. Procedures

Subjects were asked to elevate their arm approximately 5° from their 85° resting position against a hand held dynamometer to measure maximal volitional isometric contractions (MVIC) (Fig. 1). This was repeated 3 times for 5 s with a 15 s recovery between each attempt. The average of three attempts was used for each subject's final MVIC. MVIC was later used in the calculation of some of the external loads given to subjects.

Ultrasonography (General Electric LOGIQ e 2008) was used by the primary investigator to capture the linear depth of the LT and SA at rest and during lifting. In B mode, a 40 mm 8-MHz linear transducer was placed transversely on the mark previously made to identify the LT and vertically along the SA marking. Because it was observed that SA thickness increased with inspiration, the authors captured all images for the SA at the end of expiration. An on-screen caliper was used to obtain the absolute thickness of the LT and SA.

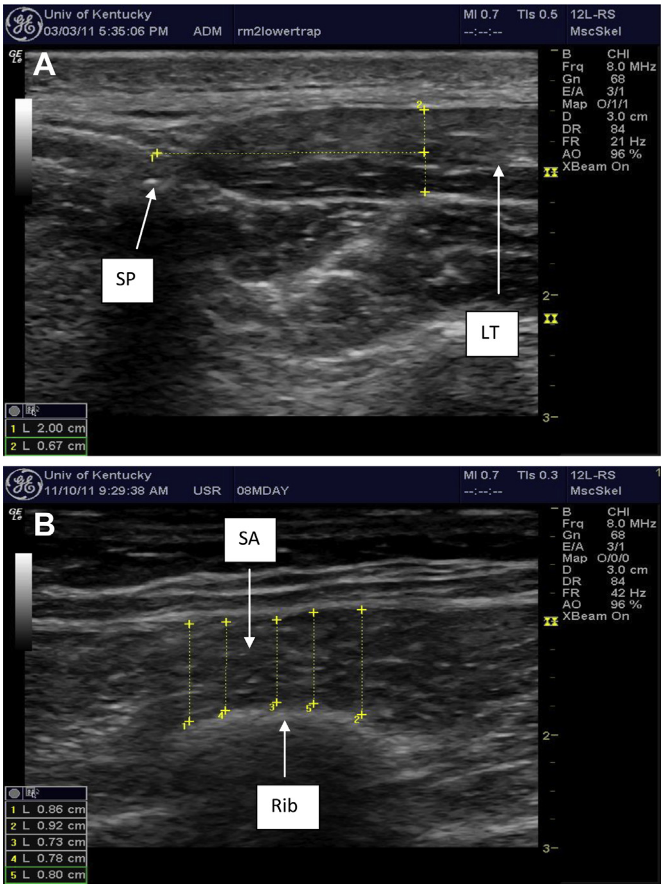

Fig. 3. A. Thickness measurement technique for the lower trapezius. The spinous process (SP) is used as a reference for measurement of the lower trapezius (LT). The horizontal perforated yellow line was drawn from the SP to a point 2 cm laterally. The vertical perforated yellow line was drawn between the two fascial borders of the LT 2 cm from the SP and represents LT thickness. B. Thickness measurement technique for the serratus anterior. The rib was used as a reference for measurement of the serratus anterior (SA). Five vertical perforated yellow lines, spaced out to encompass the width of the rib, were drawn from the rib to the superior fascial border of the SA. The average of the five measurements was used to represent SA thickness.

Next, subjects were asked to lift a series of 10 external loads with their dominate arm in random order pre-determined using the random number generator in Excel (Microsoft, Redwood, WA). An ultrasound image was captured when the subject lifted the arm off the support with no external load. Additionally, ultrasound images were captured while the subjects lifted a series of external loads (1 lb, 2 lbs, 3 lbs, 4 lbs, 25% of MVIC, 33% of MVIC, 50% of MVIC, 66% of MVIC, and 75% of MVIC). Arm elevation was performed in the same position as previously described for MVIC testing (Fig. 2A and B). This position is known to produce high SA activity and moderate LT activity (Escamilla et al., 2009). Each load was held for 2 s, and each lift was repeated to establish within day reliability. The subject rested for 30–60 s between loads. A separate investigator watched arm position and exchanged weights so that minimal transducer motion occurred. This entire series of lifting was repeated in order to obtain images from both muscles. The same methods were repeated 1 week later to establish between-day reliability.

2.5. Data organization

Linear measurements of the LT thickness were made 2 cm from the spinous process (O'Sullivan et al., 2007) (Fig. 3A). Linear measurements of the SA were made from the border of the rib up to the inside edge of the muscle border. The average of 5 thickness measures, spanning the width of the rib, was used for analysis (Fig. 3B).

We calculated torque values for each lift with the following equation:

- Arm mass (N) = ((body weight in lbs)*.051)*4.48
- Arm Torque (Nm) = Arm mass (N)*(length of arm in m)
- External mass (N) = (weight external load in lbs)*4.48
- External Torque (Nm) = external mass (N)*(length of arm in m)
- Total Torque (Nm) = Arm Torque (Nm) + External Torque (Nm)

Next, we ran a repeated measures analysis of variance (ANOVA) to determine if torque values were significantly different between the 11 conditions. The analysis revealed significant differences in torque between all conditions ($p < .001$). To reduce the number of comparisons for the data analysis of muscle thickness, the investigators chose three of these conditions to analyze: rest, arm lift with no external load, and 75% MVIC. Rest was chosen in the analysis as a baseline, while arm lifting with no external load and

Table 1
Lower trapezius thickness within and between day reliability.

Condition	Mean thickness (cm)		ICC (95% CI)	SEM (cm)	MDC (cm)
	Measure 1	Measure 2			
Rest					
W/D	.41 (.12)	.41 (.12)	.95 (.85, .98)	.03	.04
B/D	.41 (.08)	.41 (.11)	.86 (.55, .96)	.04	.06
Arm lift					
W/D	.51 (.19)	.52 (.20)	.99 (.98, 1.0)	.02	.03
B/D	.55 (.20)	.52 (.20)	.97 (.90, .99)	.03	.05
75% MVIC					
W/D	.57 (.21)	.59 (.22)	.97 (.91, .99)	.04	.05
B/D	.58 (.21)	.58 (.19)	.93 (.79, .98)	.05	.07

W/D = within day; B/D = between day; CI = confidence interval; MVIC = maximum voluntary isometric contraction; SEM = standard error of the measure; MDC = minimal detectable change. Conditions refer to the subject at rest, subject lifting the arm at 90° scaption, and subject lifting a weight equivalent to 75% MVIC.

Table 2
Serratus anterior thickness within and between day reliability.

Condition	Mean thickness (cm)		ICC (95% CI)	SEM (cm)	MDC (cm)
	Measure 1	Measure 2			
Rest					
W/D	.61 (.21)	.62 (.21)	.99 (.97, 1.0)	.02	.03
B/D	.61 (.22)	.61 (.21)	.89 (.66, .97)	.07	.10
Arm lift					
W/D	.76 (.21)	.78 (.24)	.98 (.95, .99)	.03	.05
B/D	.73 (.23)	.77 (.22)	.86 (.57, .95)	.09	.12
75% MVIC					
W/D	.76 (.26)	.77 (.25)	.94(.81, .98)	.06	.09
B/D	.79 (.24)	.76 (.25)	.91(.72, .97)	.07	.10

W/D = within day; B/D = between day; CI = confidence interval; MVIC = maximum voluntary isometric contraction; SEM = standard error of the measure; MDC = minimal detectable change. Conditions refer to the subject at rest, subject lifting the arm at 90° scaption, and subject lifting a weight equivalent to 75% MVIC.

75% MVIC represented our highest and lowest torque values respectively.

2.6. Data analysis

Muscle thicknesses of resting, arm lift with no external load, and 75% MVIC from the second day of testing were used for the within day reliability analysis. The average absolute muscle thicknesses of rest, arm lift with no external load, and 75% MVIC were used for the between-day reliability analysis. Interclass correlation coefficients (ICCs) and their 95% confidence intervals were used to determine the level of agreement both within and between day for absolute thickness calculations. The standard error of the measure (SEM) and minimal detectable change (MDC) scores were calculated for each lifting condition and each muscle. Bland and Altman plots were constructed to determine levels of agreement at rest.

Separate repeated measure ANOVAs for each muscle compared the average absolute muscle thickness for three selected conditions for testing on day 2. Finally, post hoc Bonferroni analyses were run to determine individual differences in average absolute muscle thickness. Statistical Analysis was performed using SPSS version 20 for windows (SPSS Inc. Chicago, IL).

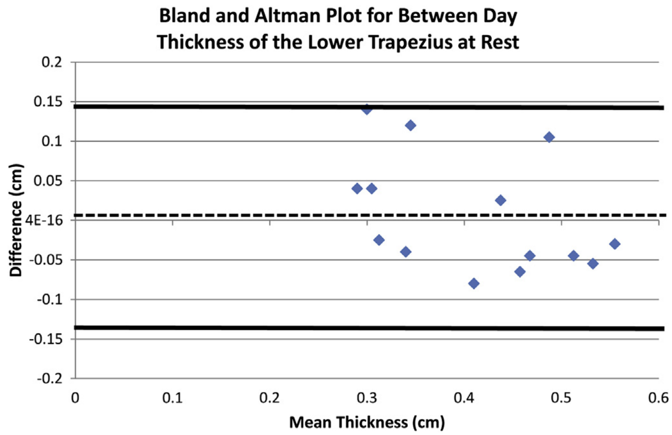

Fig. 4. Bland and Altman plot showing between-day reliability for scans of lower trapezius. The difference in muscle thickness between trial 1 and trial 2 is plotted against mean muscle thickness for each subject. The middle line shows the mean difference. The 95% upper and lower limits of agreement represent 2 standard deviations above and below the mean difference. Values for difference plotted on the *x*-axis are in centimeters.

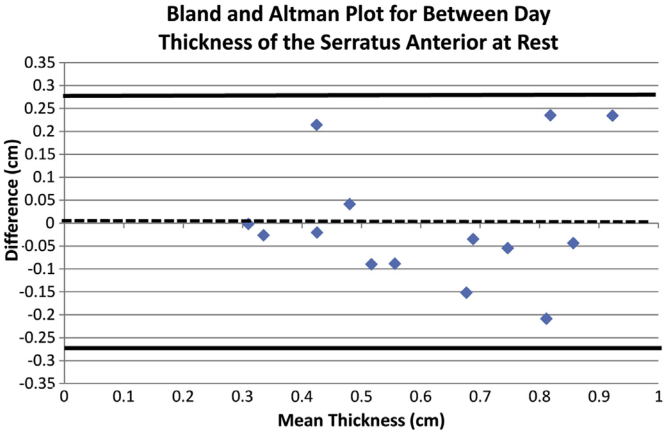

Fig. 5. Bland and Altman plot showing between-day reliability for scans of serratus anterior. The difference in muscle thickness between trial 1 and trial 2 is plotted against mean muscle thickness for each subject. The middle line shows the mean difference. The 95% upper and lower limits of agreement represent 2 standard deviations above and below the mean difference. Values for difference plotted on the *x*-axis are in centimeters.

3. Results

LT and SA within and between day ICCs, SEM, and MDC for the 3 lifting conditions are presented in Tables 1 and 2, respectively. The intra-session reliability (ICC $>$ .94) was excellent and the inter-session reliability (ICC $>$ .86) was good for both muscles at rest, arm elevation with no load, and arm elevation holding a load of 75% MVIC. Bland and Altman plot for the LT revealed a mean difference of .006 cm with no outliers. The standard deviation of the difference was .07 cm, therefore the 95% limits of agreement were −.134 cm to .146 cm (Fig. 4). Bland and Altman plot for the SA revealed a mean difference was <.000 cm and there were no outliers. The standard deviation of the difference was .138 cm, therefore the 95% limits of agreement were −.28 cm to .28 cm (Fig. 5).

Significant differences in average absolute thickness values were found for both the LT ($p < .001$) and SA ($p < .001$). The Bonferroni post hoc analysis demonstrated that there were significant differences between the resting and the 2 lifting conditions ($p < .01$) but not between the two lifting conditions for both the LT (Table 3) and SA (Table 4).

4. Discussion

This was the first study to measure absolute SA thickness and demonstrated good within and between-day reliability. The functional sitting position demonstrated good within and between-day reliability of the LT and was comparable to previous research (O'Sullivan et al., 2007). Additionally, we determined that external loads placed on the shoulder resulted in increased absolute thickness of the SA and LT as measured by RUSI.

Table 3
Post hoc testing for the lower trapezius thickness.

Comparison	Mean difference (cm)	Standard error (cm)	Significance (p)	95% CI mean difference (cm)
Rest – arm lift	−.14	.04	.01	−.24, −.03
Rest – 75% MVIC	−.18	.04	.00	−.30, −.07
Arm lift –75% MVIC	−.05	.02	.16	−.11, .01

CI = confidence interval; MVIC = maximum voluntary isometric contraction. p Values have been adjusted for multiple comparisons (Bonferroni). Conditions refer to the subject at rest, subject lifting the arm at 90° scaption, and subject lifting a weight equivalent to 75% MVIC.

Table 4
Post hoc testing for the serratus anterior thickness.

Comparison	Mean difference (cm)	Standard error (cm)	Significance (*p*)	95% CI mean difference (cm)
Rest − arm lift	−.12	.03	.01	−.21, −.03
Rest − 75% MVIC	−.17	.04	.00	−.28, −.07
Arm lift − 75% MVIC	−.06	.04	.64	−.18, .06

CI = confidence interval; MVIC = maximum voluntary isometric contraction. *p* Values have been adjusted for multiple comparisons (Bonferroni). Conditions refer to the subject at rest, subject lifting the arm at 90° scaption, and subject lifting a weight equivalent to 75% MVIC.

Although there was generally good agreement, some of the between-day ICCs had wide 95% confidence intervals (CIs), and thus reveal some sources of measurement error for both muscles. Because taking multiple measures on each image may slow down the clinical use of this tool, the researchers chose to measure each image once. However, it has been reported that reliability of measuring muscle thickness between days is improved by taking the average of 4 measures, 2 images each with two measurements (Koppenhaver et al., 2009). Therefore, taking two on-screen measures of the LT and SA thickness may narrow the CIs between days.

Our second hypothesis was that LT and SA average absolute muscle thickness would change significantly with external loads placed on the shoulder. We found RUSI was able to detect absolute changes in thickness from resting to a contracted state while exceeding MDC values. However, RUSI was unable to detect differences between a low and high load placed on the shoulder. One explanation for our findings could be that RUSI may not be sensitive enough to detect changes in muscle dimensions for higher levels of contractility during an isometric contraction (Hodges et al., 2003). Conversely, the inability of the LT and SA to respond to differences in load may be an indication that these muscles function at the same level of contractility, independent of the demand placed on the shoulder, in healthy individuals (Wattanaprakornkul et al., 2011). Overall, our results imply that RUSI may be useful in distinguishing inhibition from activation but unable to detect different levels of contractility for the LT and SA.

Our findings are consistent with another imaging study reporting minimal and non-significant increases in muscle thickness with increasing torque on the rectus femoris (Delaney et al., 2010). In contrast, other studies report high correlations between measures of muscle thickness and torque (Chi-Fishman et al., 2004; Moreau et al., 2010). These inconsistent findings may reflect the fact that other factors may be influencing muscle thickness including muscle compliance, muscle structure, or contraction of adjacent muscles (Whittaker and Stokes, 2011).

There are limitations that should be considered when interpreting the results. A change in muscle thickness may be a more representative way of comparing the differences in loads (Whittaker et al., 2007). It is often recommended that researchers use normalized values because muscle thickness is known to be influenced by gender and body mass index (Rankin et al., 2005; Springer et al., 2006). Absolute values were used in this study because resting images were not taken prior to each loaded condition. Using the same resting value for all loaded conditions may result in an erroneous change in thickness calculation because it is possible that resting thickness changes during a series of lifts. In addition to change in muscle thickness, the results of this study are not necessarily applicable to the entire SA as we measured muscle thickness of the lower fibers only.

5. Conclusion

Absolute LT and SA muscle thickness can be reliably measured within and between days using ultrasound imaging in a functional position. The differences in absolute muscle thickness for both the LT and SA were significant when comparing rest to contraction. However, there was no difference in thickness between lifting a low load and high load. Future research is needed to investigate differences in muscle thickness in pathological populations.

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