ABSTRACT

Intra-rater Reliability of Rehabilitative Ultrasound Imaging of the Erector Spinae and Gluteus Medius Muscles

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Rehabilitative ultrasound imaging (RUSI) is an evolving tool which allows non-invasive quantification of muscle function. Currently, RUSI is used primarily in abdominal and lumbar multifidus muscles, and there is a need to expand its use to other clinically relevant muscle groups. The purpose of this study was to examine intra-rater reliability of RUSI measurements of erector spinae (ES) and gluteus medius (GM) muscle thickness at rest and at submaximal contraction in healthy participants.

Methods: ES and GM muscles of 30 participants were imaged at rest and submaximal contraction. Intra-rater reliability estimates using a single and average of three measurements were also compared.

Results: ICCs for both ES and GM muscle thickness ranged between .89 to .93 for single measures and from .94 - .97 for average measures.

Conclusion: This study confirms a high intra-rater reliability of ultrasound measurements of ES and GM muscle thickness when an average of three measures are used.
Intra-rater Reliability of Rehabilitative Ultrasound Imaging of the Erector Spinae and Gluteus Medius Muscles

by

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A Thesis

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CHAPTER ONE

Introduction

Musculoskeletal pain is the second largest cause of disability worldwide (Briggs et al., 2018; Woolf, 2012). More specifically, low back pain (LBP) is the most common diagnosis and a leading cause of global economic burden (Blyth et al., 2019; Deyo et al., 2006; Wu et al., 2020). As many as 60% of people with LBP have associated physical disability and high rates of hospital utilization (Drazin et al., 2016; Edwards et al., 2018; Heliövaara et al., 1989; Hospital Admissions for Acute Low Back Pain - Needs - 2019 - Internal Medicine Journal - Wiley Online Library, n.d.). The impact of LBP on work productivity and wages is estimated at $100 billion per year in the United States alone (Katz, 2006; L. H. Kim et al., 2019; Shraim et al., 2015). Imaging is a crucial aspect of evaluation and effective treatment of musculoskeletal conditions like LBP. Traditionally, computed tomography (CT), magnetic resonance imaging (MRI), and radiography have been the gold standard imaging tools for these conditions. However, each of these techniques come with their own set of limitations (Roll, 2015). MRI and CT are expensive tools that require substantial training to operate. Radiographs increase patient exposure to radiation. Additionally, these modalities are typically used for static imaging, have many contraindications, take up clinic space and cannot be used to get continuous real-time feedback during the rehabilitation process. An alternative imaging tool is rehabilitative ultrasound imaging (RUSI). This innovative technique can be used to image, evaluate, and train individuals during rehabilitation with much cheaper costs and a smaller clinic
footprint (Roll, 2015). Furthermore, this tool captures both static images and provides
dynamic real-time feedback. Numerous studies have shown the utility of RUSI for
identifying aberrant muscular contraction patterns, muscle atrophy, fasciculations, disc
pathology, and improving biofeedback for muscular activation (Lin et al., 2021; Zaidman
et al., n.d.). These studies have linked the use of RUSI to improved clinical outcome and
reduced cost of LBP management (Gilbert et al., 2004; Lanza, 2020; Lin et al., 2021;
Zaidman et al., n.d.).

Originally developed in the 1980s (Huang et al., 2014), RUSI was used in a limited
scope for obstetrics, pelvis examination, cardiology, and ophthalmology (Carovac et al.,
2011). In the last three decades it has become a useful tool in orthopedic and physical
medicine settings to explore morphology, function, and pathology of musculoskeletal
tissue (D. Teyhen & Koppenhaver, 2011; Whittaker & Emery, 2014). The reliability and
validity of RUSI as a non-invasive tool for measuring the components of muscle function
have been confirmed by several comparison studies (C.-Y. Kim et al., 2014). Research has
shown high positive correlation between RUSI and electromyography (EMG)
demonstrating its utility for measuring muscle activation (C.-Y. Kim et al., 2014;
MacKenzie et al., 2014). In 2009, Koppenhaver et al performed a systematic review
including 37 studies that investigated criteria-related validity, construct validity and
sensitivity to change of RUSI to measure trunk muscle size and activation during isometric
submaximal contraction (S. L. Koppenhaver, Hebert, Parent, et al., 2009). Ten out of those
37 studies investigated criterion related validity and concluded that RUSI had a strong
positive correlation with MRI and EMG measures of trunk muscle. Although these studies
clarified that the validity of RUSI is context dependent based on the type of muscle
involved, and intensity of contraction. Twenty three studies confirmed construct validity of RUSI to differentiate participants with and without back pain, anthropometry, and postures (S. L. Koppenhaver, Hebert, Parent, et al., 2009).

While research has documented the ability of RUSI to measure muscle function, the majority of applied clinical research has focused on the transversus abdominis and lumbar multifidus (Hides et al., 1995; Kidd et al., 2002; S. L. Koppenhaver, Hebert, Fritz, et al., 2009). Little has been done to extend the scope into other muscle groups. This is particularly striking in the erector spinae (ES) and gluteus medius (GM) because these are two key muscle groups known to play an important role in LBP (Falla et al., 2014; Farasyn & Meeusen, 2005; Kameda et al., 2020; Sadler et al., 2019; Stokes et al., 2007). The ES muscles function to extend the vertebral column. GM muscle contraction causes abduction in the hip joint during open chain movements and maintains pelvic stability during the stance phase of gait. Studies have reported differences ES and GM function for LBP patients (Farasyn & Meeusen, 2005; Kameda et al., 2020; Sadler et al., 2019; Stokes et al., 2007). People with LBP show aberrant ES muscle contraction patterns during dynamic and static tasks (Abboud et al., 2014; Falla et al., 2014). In the GM there is decreased thickness, cross-sectional area, and contraction strength during spinal loading for people with LBP (Cooper et al., 2016; Sadler et al., 2019). Therefore, the purpose of this study was to estimate the intra-rater reliability of RUSI measurements of ES and GM thickness at rest and at submaximal contraction in healthy participants. Additionally, we compared the intra-rater reliability estimates using a single measurement and an average of three measurements. Finally, t-tests were used to compare resting and contracted thickness of both ES and GM muscles to assess the ability of RUSI to detect a true difference.
CHAPTER TWO

Methods

Participants

Thirty participants of age 18 years and above, (24) men and (6) women, were recruited through flyers distributed around the campus of Baylor University, Waco. Sample size calculations were done using a web-based sample size calculator for reliability estimates to determine the number of participants required for this study (Walter et al., 1998). This calculation required specific values for minimum acceptable reliability (ICC), expected reliability (ICC), significance level, power, number of repetitions per subject and expected dropout rate which were 0.75, 0.90, 0.05, 80%, 3, and 15% respectively. Participants were included if they were able to lie prone and in side-lying for a minimum of 20 minutes, if they were able to perform raising both arms in prone, and lifting the right foot just off the test table in side-lying position. Participants were excluded if they had current hip or back pain that was debilitating or prevented them from participating in activities of daily living. These included getting out of bed in the morning, walking upstairs, going to the bathroom, or picking up objects from the floor. Participants were also excluded if they had previous significant back/hip injury or surgery, such as spinal or hip fracture, lumbar or hip surgery.

Examiner

All RUSI measures were performed by a single examiner: a licensed physical therapist (PT) with no previous experience in RUSI. 6 hours of hands-on training was done
with faculty co-investigator experienced with RUSI. This was followed by an additional three months of individual practice on 20 volunteers that included feedback from the co-investigator. Total instruction and training time was estimated to be 40 hours. Examiner also performed pilot assessments on 10 healthy participants for methodology refinement.

**Procedures**

The RUSI device used in this study is a Butterfly iQ+ (2020 Butterfly Network inc., Burlington, Massachusetts). Imaging began with the right ES for all participants. Participants were relaxed in prone with their arms overhead (Figure 1). During imaging,

![Figure 1. RUSI imaging of ES muscle procedure](image)

the examiner first identified the hump like appearance produced by transverse processes. The ultrasound transducer was placed 4-5 cm lateral from the spinous process i.e. base of transverse process of L4, and the head of ultrasound probe was titled towards the midline (Figure 1). After an image of the participant’s ES was taken at rest, they were then instructed to perform submaximal contraction of the ES i.e. raise both of their arms from
the test table while lying prone and holding the position until imaging was done. Participants were then instructed to move to the left side-lying position to image GM at rest and at submaximal contraction. In the side-lying position the hip and knee were in neutral, and the right hip joint was in approximately 20 – 25 degrees of adduction (Figure 2). During imaging, the transducer was positioned on the lateral aspect of the hip located at 25% of the distance between the ASIS and PSIS, and on top of the greater trochanter (Figure 2). The examiner identified the head of femur, gluteus minimus and GM in the ultrasound imaging. To achieve sub-maximal contraction, participants were asked to raise their right foot just off the ground. Clear instructions were provided to the participants on lifting the foot no more than a centimeter from the test table to ensure that contraction was submaximal. Each participant had to hold the contraction for 5 - 6 seconds while their muscles were being imaged. A rest of 40 – 50 seconds was provided in between each repetition.
This method was repeated two more times for both muscles until a total of twelve different images for each participant was obtained: three at rest and three at contraction. These twelve images completed the image collection process.

Measurements

After data collection, the images were downloaded to a laptop computer and measured using Image J software (V1.38t, National Institutes of Health, Bethesda, Maryland). The thickness of ES was measured from the lower border of the superficial fascia to the upper border of articular processes which appeared as a bright hyperechoic hump spanning the width of the screen (Figure 3). GM thickness was measured from the lower border of the superficial fascia to upper border of the fascia that separated GM from

Figure 3. Images of ES at rest and contraction
underlying gluteus minimus (Figure 4). Measurements were done at the center of the image to prevent distortion effect and reported in centimeter. This process was repeated on every image.

**Statistical Analysis**

All data were analyzed with SPSS Version 28 software (Chicago, IL). Descriptive statistics were performed on age, sex, height, and weight. Variables included in the main analysis were resting thickness, contracted thickness, and percent thickness change of the ES and GM muscles. Percent thickness change was calculated by the equation \((\text{Thickness}_{\text{contracted}} - \text{Thickness}_{\text{rest}})/\text{Thickness}_{\text{rest}}\).

Intraclass correlation coefficients (ICCs) with 95% confidence interval (CI) were calculated to assess intra-rater (model 3,1 and 3,3) reliability. Based on previous work investigating RUSI of reliability of abdominal muscles, the mean of three measures was
used as the analysis of interest for intra-rater reliability (S. Koppenhaver, Parent, Teyhen, et al., 2009). ICC measures of percent thickness change for both ES and GM were calculated. Means for ES and GM thickness at rest and contraction were calculated for t-test analyses. Reliability was further assessed by calculating standard error of measurement (SEM) and minimal detectable change (MDC). To quantify measurement error, SEM was calculated as (SD × √[1-ICC]) using the ICC estimates for intra-rater reliability. MDC defines the smallest change in the measured thickness which needs to be observed for there to be 95% confidence that the observed change in muscle thickness is real and not a product of measurement error or random variation in the method (de Vet et al., 2006). MDC was calculated using the formula (1.96* SEM* √2).
CHAPTER THREE

Results

Demographic information on age, sex, height, and weight are listed in Table 1.

Table 1. Baseline Demographic Information

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean +/- SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>25.9 ± 6.5</td>
</tr>
<tr>
<td>Weight, lbs</td>
<td>153.2 ± 29.2</td>
</tr>
<tr>
<td>Height, cm</td>
<td>171.5 ± 10.2</td>
</tr>
<tr>
<td>Sex, % women</td>
<td>20%</td>
</tr>
</tbody>
</table>

Abbreviations: y = year, lbs = pounds, cm = centimeter

Mean ES and GM muscle thickness values and percent thickness change from rest to contraction are listed in Table 2. Point estimates (ICCs) for ES thickness measurements ranged between -.89 -.93 for single measurement and from .96 -.97 for average measurement of resting and contraction thickness respectively. Similarly, point estimates (ICCs) for GM ranged from .85 -.87 for single measurement and from .94 -.95 for average measurement for resting and contraction thickness respectively (Table 2).
Table 2. Reliability of Erector Spinae and Gluteus Medius RUSI measures

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Mean +/- SD</th>
<th>Single ICC (95%CI)</th>
<th>Average ICC (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Erector Spinae</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed Thickness</td>
<td>2.88 +/- .46 cm</td>
<td>.93 (.88-.96)</td>
<td>.97 (.95-.98)</td>
</tr>
<tr>
<td>Contracted Thickness</td>
<td>3.19 +/- .50 cm</td>
<td>.89 (.81-.94)</td>
<td>.96 (.93-.98)</td>
</tr>
<tr>
<td>% Thickness Change</td>
<td>11 +/- 8.45%</td>
<td>.61 (.40-.77)</td>
<td>.82 (.67-.91)</td>
</tr>
<tr>
<td><strong>Gluteus Medius</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed Thickness</td>
<td>3.01 +/- .39 cm</td>
<td>.87 (.78-.93)</td>
<td>.95 (.91-.97)</td>
</tr>
<tr>
<td>Contracted Thickness</td>
<td>3.24 +/- .41 cm</td>
<td>.85 (.75-.92)</td>
<td>.94 (.90-.97)</td>
</tr>
<tr>
<td>% Thickness Change</td>
<td>8 +/- 4.99%</td>
<td>.32 (.09-.57)</td>
<td>.59 (.23-.80)</td>
</tr>
</tbody>
</table>

Reliability of percent thickness change for single measurement (ICC = .61) and average measurement (ICC= .82) for ES, as well as single measurement (ICC= .32), and average measurement (ICC= .59) for GM, was lower (Table 2) (Koo & Li, 2016). Estimates of measurement error for ES thickness were .08 cm to .12 cm in resting and .10 cm to .17 cm for contracted measures (Table 3). Estimates of measurement error for GM thickness were .09 cm to .14 cm in resting and .10 cm to .16 cm for contracted measures (Table 3). Estimates of measurement error for percent thickness change in ES were 3.59% for an average measure and 5.28% for a single measure. In GM these were 3.20% for an average
and 4.11% for a single measure. Estimates of MDC for ES thickness were .22 cm to .33 cm in resting and .28 cm to .47 cm for contracted state (Table 3). Estimates of MDC for GM thickness were .25 cm to .39 cm in resting and .28 cm to .44 cm for a contracted state (Table 3). Estimates of MDC for percent thickness change for ES were 9.95% for an average measure and 14.64% for a single measure and for GM were 8.87% for an average and 11.39% for a single measure. Paired t-tests comparing resting with contracted thickness

<table>
<thead>
<tr>
<th>Muscles</th>
<th>SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single</td>
<td>Average</td>
</tr>
<tr>
<td>Erector Spinae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed Thickness</td>
<td>.12cm</td>
<td>.08cm</td>
</tr>
<tr>
<td>Contracted</td>
<td>.17cm</td>
<td>.10cm</td>
</tr>
<tr>
<td>% Thickness Change</td>
<td>5.28%</td>
<td>3.59%</td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed Thickness</td>
<td>.14cm</td>
<td>.09cm</td>
</tr>
<tr>
<td>Contracted</td>
<td>.16cm</td>
<td>.10cm</td>
</tr>
<tr>
<td>% Thickness Change</td>
<td>4.11%</td>
<td>3.20%</td>
</tr>
</tbody>
</table>
demonstrated significant differences between the measures for both ES ($t = 7.74, p < 0.001$) and GM ($t = 8.93, p < 0.001$). Images from two different participants could not be measured for both ES and GM because the bony landmarks in those images were not clearly identifiable. The total number of participants whose images could be measured were 28 for both ES and GM.
CHAPTER FOUR
Discussion

This study estimated the intra-rater reliability of RUSI to measure thickness of ES and GM at rest and at submaximal contraction. We also compared the intra-rater reliability between a single measurement and an average of three measurements. Participants did not have any history of back pain limiting them from activities of daily living. Study participants were able to perform test activities without any pain or restriction in their range of motion. When measuring muscle thickness, previously published studies have consistently reported optimal measurement precision when an average of two or more measurements were used (S. Koppenhaver, Parent, Teyhen, et al., 2009; Larivière et al., 2013; Skeie et al., 2015; Wong et al., 2013). However, it is important to observe if this is necessary for patients in clinical settings, where taking an average of three measurements might not be always practical.

Our result demonstrated good intra-rater reliability (ICC > .84) of RUSI imaging from single measures of both ES and GM thickness at rest and at submaximal contraction (Koo & Li, 2016). Moreover, the reliability estimates were significantly higher for both ES and GM resting and contracted thickness (ICC > .93) when an average of three measurements were computed. This suggests that the measurement is highly reliable when an average of three trials of ES and GM are taken, during both rest and contraction state. The reliability estimates of percent thickness change were also higher for average measures when compared to single measures (ICC_{average} > ICC_{single}).
Overall, the reliability estimates of percent thickness change were poor for both muscles (ICC < .83) which has been linked to compounding of measurement error from both resting and contracted conditions (S. Koppenhaver et al., 2015; S. L. Koppenhaver, Parent, Teyhen, et al., 2009; Narouei et al., 2016). Measurement error during RUSI is likely from multiple factors including lack of standardization in muscle contraction procedure leading to chances of higher variability in contraction intensity of each test muscle (S. Koppenhaver et al., 2015). Lack of sufficient experience and error due to manual probe handling could also be a potential cause for lower reliability of percent thickness change (Wong et al., 2013). Ability to maintain the constant contact pressure of transducer during submaximal contraction of muscles is associated with acquiring a flattened image (Hoppes et al., 2015). It was difficult to maintain the same contact pressure throughout the three trials of measurements with the transducer positioned perpendicular to skin especially for GM muscle testing.

To our knowledge there has been only one other study that measured intra-rater reliability of GM thickness at rest and during contraction using RUSI (Whittaker & Emery, 2014). Reliability estimates of an average of three measurements both at rest and contraction for GM (ICC > .90) was similar to our findings (Whittaker & Emery, 2014). In the same study, they also calculated reliability of percent thickness change (ICC = .54 - .84) which was relatively lower than the reliability of resting or contracted thickness. Factors like adjacent muscle pressure (DeJong et al., 2020; Delaney et al., 2010), difference in connective tissue elasticity can cause differences in muscle thickening behavior (Dieterich et al., 2014). Different methods of muscle contraction strategies adopted in different studies can produce variable results in thickness change in the same muscle. Therefore, it is
important to find out the relationship between muscle activity level and thickness change before comparing different study results. Other ultrasound studies done on GM muscle have only looked into muscle functional-activation ratios, ultrasound guided drug injection procedures for inflammatory GM conditions and estimation of GM muscle activity levels (DeJong et al., 2020; Dieterich et al., 2014; Labrosse et al., 2010). RUSI studies on GM muscle characteristics like thickness at rest and while performing different activities are insufficiently documented.

The reliability findings from our study for ES are comparable to the few other studies done in this area. One previous study looked at intra-rater reliability of ES muscle thickness at rest using an average of two measures and found good intra-rater reliability (ICC = .88 - .94) (Nanikawa & Miyazaki, 2019). These results have also been replicated in a study of ES thickness at three different lumbar postures (maximum flexion, neutral and maximum extension) (Watanabe et al., 2004). A moderate correlation between RUSI and MRI measures of ES thickness have been reported by prior intra-rater reliability studies (Belavy et al., 2015).

Studies done in other muscle groups also support the findings from this study. Koppenhaver et al (2009) reported good intra-rater reliability with an average of two measures of RUSI in transversus abdominis and lumbar multifidus thickness (ICC > .90). These studies also had lower estimates of percent thickness change similar to our findings. As previously stated, the lower reliability estimates in percent thickness change is due to combination of measurement errors from both resting and contracted thickness instead of just one measure (S. L. Koppenhaver, Hebert, Fritz, et al., 2009; Whittaker & Emery, 2014). Researches have reported high intra-rater (ICC 0.96 and 0.98) and inter-rater (ICC 0.87 and
0.92) reliability of RUSI measurements of infraspinatus muscle thickness in rested and a contracted state (S. Koppenhaver et al., 2015). Similarly, a study done to measure gluteus maximus muscle thickness using RUSI, at rest and during contraction also reported good intra-rater reliability (ICC >0.870) (Jeong et al., 2017). Hebert et al performed a systematic review including 24 studies on reliability of RUSI assessing trunk and abdominal muscles and reported good intra-rater and inter-rater reliability (ICC: >0.90) (Hebert et al., 2009). Teyhen et al (2005) reported good intra-reliability (ICC = 0.93-0.97) using RUSI to measure transversus abdominis thickness at rest and during abdominal drawing-in maneuver (ADIM) in LBP patients. Pressler et al (2006), looked into cross-sectional area of lumbar multifidus muscle on 14 healthy female participants and reported a moderate to good (ICC = 0.72-0.99) intra-rater reliability. Hides et al (2007) examined thickness of transversus abdominis and internal oblique muscles using RUSI to investigate intra-rater reliability both at rest and during ADIM. Is this study they used the mean of four to six measurements and reported moderate to good (ICC = 0.62-0.85) intra-rater reliability (Hides et al., 2007).

The overall conclusion from our study and the body of existing literature supports good intra-rater reliability for RUSI measurements of muscle morphology and function. Most RUSI studies done to date are on lumbar and abdominal muscles (Hides et al., 1995; Huang et al., 2014). Our study adds to the literature by extending this research into ES and GM muscle groups. The intra-rater reliability of RUSI measurement of ES and GM are excellent with the use of average measurements. Additional research is required with varied test position and a greater number of participants to identify and thereby eliminate different possible sources of measurement errors. There are no RUSI studies done solely on GM and ES thickness comparing participants with and without LBP. The data and findings in this
study can be used in future investigations to do a comparative RUSI study of GM and ES thickness on participants with LBP.

A final aspect of this study was assessing differences in muscle thickness between rested and sub maximal contracted states. We found statistically significant differences between muscle thickness for resting and contracted states in both ES and GM. This suggests that RUSI was able to detect a real change in muscle thickness between these states. The SEM and MDC were lower for average measures when compared to single measures for both muscles. From the mean percent thickness change and MDC values, a participant would have to increase ES muscle thickness from 11% to 25.64% if a single measure was used, and 11% to 20.95% if a mean of three measures were used. Similarly, a participant would have to increase the percent thickness change in GM muscle thickness 8% to 19.39% if a single measure were used, and from 8% to 16.87% if a mean of three measures were used.

We also measured MDC and SEM values for muscle thickness single and average measure as done by some other studies in the past. Similar results have been found in other reliability studies using RUSI in the biceps brachii and triceps brachii (Hahn et al., 2017). This study found an SEM of 0.303 to 0.866 mm and an MDC of 0.84 to 2.40 mm for resting thickness and contraction respectively. In a study done by Arab et al. (2013) on abdominal muscles with and without chronic LBP, SEM values ranged from 0.19 to 0.55 mm and MDC values ranged from 0.52 to 1.51 mm between supine and sitting. Finally, May et al (2021) reported a 3.2 mm MDC for RUSI measurement of gastrocnemius medialis muscle based on a rested state. This helps clinicians to understand the spatial resolution and degree of change which can be accurately detected by RUSI. Future research needs to be done to
assess the percent change in muscle thickness which may be associated with dysfunction or with significant improvement during rehabilitation.

Limitations

There are several limitations to this study. First, it is an intra-rater study done by single examiner on the same day. Multiple sessions on different days performed by different examiner would be beneficial to test the reproducibility of the methods, identify additional sources of errors and to confirm its clinical applicability. Second, the study was done on healthy/ asymptomatic people and there was no documentation of participants regular exercise routine. This could affect muscle activation, thickness changes and again could have helped in identifying additional sources of measurement errors (Goodpaster et al., 2008; Westerberg et al., 2018). Third, there was no standardization to ensure the submaximal contraction equated solely to GM muscle activation to support limb weight. Use of a blood pressure cuff or similar device to ensure the foot was not partially resting on the table would have aided in defining the submaximal contraction level across participants. Lastly, the study participants were mainly young adult males and lacked diversity in terms of age, and gender, which limits generalizability. Future studies should be conducted with larger sample sizes and include a more diverse population. Further studies involving both participants with and without LBP should be considered to get more clinically applicable result.
CHAPTER FIVE

Conclusion

RUSI measurements of ES and GM muscles thickness done by single examiner appear to be highly reliable, both at rest and during contraction when the average of three measurements are taken. Error of measurement and MDC in percent thickness change also decreases when using the mean of three measures. RUSI also demonstrated an ability to detect a real difference in muscle thickness between resting and contracted states. Therefore, to optimize the reliability using an average of three measures is recommended. Future studies are needed on larger and more diverse samples to enhance the reproducibility of ES and GM RUSI measures. Additionally, studies comparing participants with and without LBP are needed to ascertain meaningfulness of ES and GM RUSI measures within clinical settings.


