



University of Kentucky
UKnowledge

Theses and Dissertations--Rehabilitation
Sciences

Rehabilitation Sciences

2013

Scapular Muscle Assessment in Patients with Lateral Epicondylalgia

Joseph M. Day
day_matt@hotmail.com

[Right click to open a feedback form in a new tab to let us know how this document benefits you.](#)

Recommended Citation

Day, Joseph M., "Scapular Muscle Assessment in Patients with Lateral Epicondylalgia" (2013). *Theses and Dissertations--Rehabilitation Sciences*. 16.
https://uknowledge.uky.edu/rehabsci_etds/16

This Doctoral Dissertation is brought to you for free and open access by the Rehabilitation Sciences at UKnowledge. It has been accepted for inclusion in Theses and Dissertations--Rehabilitation Sciences by an authorized administrator of UKnowledge. For more information, please contact UKnowledge@lsv.uky.edu.

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained and attached hereto needed written permission statements(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine).

I hereby grant to The University of Kentucky and its agents the non-exclusive license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless a preapproved embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's dissertation including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Joseph M. Day, Student

Timothy L. Uhl, Major Professor

Ann D. Olson, Director of Graduate Studies

SCAPULAR MUSCLE ASSESSMENT IN PATIENTS WITH LATERAL
EPICONDYLALGIA

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in the College of Health Sciences
at the University of Kentucky

By

Joseph M. Day

Lexington, Kentucky

Co-Directors: Dr. Timothy L. Uhl, Associate Professor of Athletic Training and Dr.

Arthur J. Nitz, Professor of Physical Therapy

Lexington, Kentucky

2013

Copyright © Joseph M. Day 2013

ABSTRACT OF DISSERTATION

SCAPULAR MUSCLE ASSESSMENT IN PATIENTS WITH LATERAL EPICONDYLALGIA

The role rehabilitation plays in the management of patients with lateral epicondylalgia (LE) remains elusive secondary to high recurrence rates. Addressing scapular muscle deficits may be important in the rehabilitation of patients with LE. However, it is unknown if scapular muscle impairments exist in a working population of patients with LE. The purpose of this dissertation was to assess scapular muscle strength and endurance in a working population of patients with LE.

Clinical scapular muscle assessment tools are limited in their ability to isolate specific muscles. Rehabilitative ultrasound imaging (RUSI) is a potentially useful tool but few studies have investigated its utility. Absolute muscle thickness measurements were obtained on healthy individuals for the lower trapezius (LT) and serratus anterior (SA) under three conditions (arm at rest, arm elevated with a low load, arm elevated with a high load). For both the LT and SA, a significant distinction could be made in muscle thickness between rest and a loaded condition but not between the two load conditions. Furthermore, excellent reliability was demonstrated for both muscles.

It is unknown whether arm dominance plays a role in scapular muscle assessments. Therefore, healthy individuals between the ages of 30 and 65 were recruited to compare the effect of arm dominance on scapular muscle strength, endurance, and change in thickness measured by RUSI. Results indicate that arm dominance does significantly affect some measures of scapular muscle strength and endurance. However, the differences between the dominant and non-dominant limbs were not beyond measurement error.

Scapular muscle strength, endurance, and change in muscle thickness of the LT and SA were assessed in 28 patients presenting with signs and symptoms consistent with LE. LT strength, SA strength, middle trapezius strength, endurance, and change in SA thickness were significantly less in patients with LE compared to matched controls. SA and LT strength were significantly less in the involved limb compared to the uninvolved limb in patients with LE. The results suggest that assessing scapular muscle endurance as well as LT and SA strength is indicated when evaluating patients with LE, and the results should be compared to normative data.

KEYWORDS: serratus anterior, trapezius, strength, endurance, rehabilitative ultrasound imaging

Joseph M. Day
Student's Signature

August 1, 2013
Date

SCAPULAR MUSCLE ASSESSMENT IN PATIENTS WITH LATERAL
EPICONDYLALGIA

By

Joseph M. Day

Timothy L. Uhl, Ph.D.

Co-Director of Dissertation

Arthur J. Nitz, Ph.D.

Co-Director of Dissertation

Ann D. Olson, Ph.D.

Director of Graduate Studies

August 1, 2013

Date

ACKNOWLEDGEMENTS

Phil Jackson, arguably the most successful NBA coach, describes team as “the collective strengths of each individual member.” Through my academic experiences over the last 4 years, I am convinced the “team approach” provides superior results for any goal because a team protects against individual weaknesses. Similar to basketball, it takes the strengths of several individual members working as a cohesive unit to achieve academic success. I have been truly blessed with a team of individuals that have been willing to share their strengths.

My dissertation committee has dedicated an abundance of time and energy to ensure my academic success. My co-chairs Tim Uhl and Art Nitz were always willing to assist me in my efforts even when there wasn't time. As a mentor, Tim has trained me to problem solve and taught me that an individual can better themselves by taking chances. As a model academic, Tim portrayed the perfect combination of educator and researcher, while always keeping a clinical perspective. Art has successfully encouraged me to focus on a specific rehabilitation topic and become an expert. He has also trained me to be a critical consumer of the literature and to think independently. Joe Stemple has offered a unique perspective on clinical research and provided important feedback in writing as an academic. Heather Bush provided me some of the best practical statistical knowledge that I will be able to share with others. Finally, I would like to extend a thank you to my outside reader, Robert Shapiro.

The support and encouragement of my fellow colleagues has also propelled me to my final goal. In particular, I would like to thank members of the Rehabilitation Sciences Upper Extremity Research Team, Stephanie Moore, Enrique Smith-Forbes, and Aaron

Sciascia for their genuine concern and practical feedback over the past four years. I would also like to thank Dia Sugimoto for being one of the most genuine and encouraging friends I have ever known. Finally, to Mary Fisher, who lead by example and showed me that a Ph.D. was possible with a family.

I would like to extend a special thank you to my colleagues at Kentucky Hand and Physical Therapy. In particular, I would like to extend my gratitude to the owners of KHPT for providing funding and supporting my research endeavors. Greg Pitts helped me grow as a clinician by sharing his expertise in hand rehabilitation. I would especially like to thank Michelle McCallum and Ryan Foister for their loyal support in assisting me with data collection.

I would never be in the position I am today without my immediate family. To my dear wife, Bethany, who pulled double time as a provider and mother so that my dream could be realized. To my children, Lucas and Melayna, who somehow seemed to understand when I had to brush them aside to finish another project. Even in rough times, it was comforting to know that I could always count on the unconditional love of my family.

Table of Contents

Acknowledgements	iii
List of Tables.....	ix
List of Figures	x
List of Appendices.....	xi
Chapter 1 : Introduction.....	1
Background.....	1
Problem	6
Purpose and Aims	7
Clinical Implications	9
Operational Definitions	10
Assumptions	11
Delimitations	11
Chapter 2 : Review of the Literature	12
Introduction	12
Efficacy of Conservative Treatment Approaches for LE.....	12
The Kinetic Chain Theory and Lateral Epicondylalgia	14
Shoulder girdle impairments and lateral epicondylalgia	17
Kinetic Link Between Scapular Musculature and Lateral Epicondylalgia.....	18
Limitations	21
Future Studies.....	22
Summary.....	23
Clinical Measures of Scapular Muscle Strength and Endurance.....	23
Ultrasound Imaging in the Assessment of scapular musculature	26
Chapter 3 : Thickness of the Lower Trapezius and Serratus Anterior Using Ultrasound Imaging During a Repeated Arm Lifting Task	29
Introduction	29
Methods.....	31
Subjects:.....	31
Subject Preparation:.....	31
Muscular Identification.....	31

Procedures:.....	32
Data Organization:	34
Data Analysis:	36
Results	36
Discussion:	41
Conclusion:.....	43
Chapter 4 : A Comparison of Dominant and Non-dominant Scapular Muscle Strength, Endurance, and Change in Muscle Thickness.....	44
Introduction	44
Methods.....	46
Experimental Approach to the Problem:	46
Subjects:.....	47
Procedure	48
Statistical Analyses:.....	54
Results:	55
Reliability.....	55
Dominant to Non-dominant Comparisons.....	55
Discussion:	58
Strength with a HHD	59
Scapular Muscle Endurance.....	61
Rehabilitative Ultrasound Imaging	62
Limitations	64
Conclusion:.....	64
Chapter 5 : Scapular Muscle Assessment in Patients with Lateral Epicondylalgia	65
Introduction:	65
Methods.....	67
Subjects:.....	67
Procedures:.....	69
Statistical Analyses.....	75
Results	78

Comparison Between LE patients and the Control Group for Strength, Endurance, and Change in Muscle Thickness.....	79
LE involved to uninjured comparison.....	82
Discussion:	84
Scapular Muscle Strength and Endurance in Patients with LE.....	84
LT and SA muscle thickness measured by RUSI	88
Limitations	90
Conclusion:.....	92
Chapter 6 Summary	93
Hypotheses and Findings for Specific Aim 1	93
Hypotheses and Findings For Specific Aim 2.....	94
Hypotheses and Findings for Specific Aim 3.....	95
Synthesis and Application of Results.....	95
Appendices.....	100
Appendix A: Consent Form.....	100
Appendix B: Medical History and Demographics for Normal Controls	103
Appendix C: Medical History and Demographics for Patients	104
Appendix D: Survey of Upper Extremity Disability Quick (DASH)	106
Appendix E: Patient Rated Tennis Elbow Evaluation	107
Appendix F: Explanation for Endurance Testing	109
Appendix G: Psychometric Properties for a 2lb Lifting Condition Performed with Ultrasound Imaging not Reported in Chapter 3.....	110
Appendix H: Between Day Trends for the Scapular Muscle Endurance Test in Healthy Individuals	111
Appendix I: Comparison of Mean Scapular Muscle Strength Values Recorded in Chapter 4 to Previously Reported Data.....	112
Appendix J: Comparison of Absolute Serratus Anterior Thickness Values Across Studies	113
Appendix K: Mean Heart Rates and Standard Deviations for LE patients and Controls During Data Collection	114
Appendix L: Comparison of Mean Scapular Muscle Strength Values Recorded for LE Patients in Chapter 5 to Previously Reported Data on Patients with Shoulder Pathology	115

References.....	116
Vita	127

List of Tables

Table 3.1: Lower Trapezius Thickness Within and Between Day Reliability.....	39
Table 3.2: Serratus Anterior Thickness Within and Between Day Reliability	39
Table 3.3: Post Hoc Testing for the Lower Trapezius Thickness	40
Table 3.4: Post Hoc Testing for the Serratus Anterior Thickness.....	40
Table 4.1: Subject Demographics	56
Table 4.2: Within Day Reliability for Hand Held Dynamometer Scapular Muscle Tests	57
Table 4.3: Between Day Reliability for the Scapular Muscle Endurance Test.....	57
Table 4.4: Marginal Mean Muscle Thickness Outcomes and Differences Between Limbs	57
Table 4.5: Unadjusted Mean Muscle Thickness Outcomes and Differences Between Limbs	58
Table 5.1: Patient Characteristics for Strength and Endurance Comparison.....	78
Table 5.2: Patient Characteristics for Muscle Thickness Comparisons	79
Table 5.3: Between Group Comparison of Marginal Mean Values of Scapular Muscle Thickness	82
Table 5.4: Within LE Group Comparison of Marginal Mean Values of Scapular Muscle Thickness	84
Table 5.5: Between Group Comparison of Unadjusted Mean Values of Scapular Muscle Thickness	89

List of Figures

Figure 2.1: Linking Scapular Muscle Dysfunction with Lateral Epicondylalgia	19
Figure 3.1: Resting Subject Position and Probe Placement for the Lower Trapezius.....	33
Figure 3.2: Resting Subject Position and Probe Placement for the Serratus Anterior	33
Figure 3.3: Thickness Measurement Technique for the Lower Trapezius	34
Figure 3.4: Thickness Measurement Technique for the Serratus Anterior.....	35
Figure 3.5: Bland and Altman Lower Trapezius.....	37
Figure 3.6: Bland and Altman Serratus Anterior	38
Figure 4.1: Upper Trapezius Strength Testing.....	51
Figure 4.2: Serratus Anterior Strength Testing	51
Figure 4.3: Middle Trapezius Strength Testing	51
Figure 4.4: Lower Trapezius Strength Testing	51
Figure 4.5: Scapular Muscle Endurance Test	52
Figure 4.6: Dominant versus Non-dominant Scapular Muscle Strength.....	58
Figure 5.1: Serratus Anterior Strength Testing	71
Figure 5.2: Middle Trapezius Strength Testing	71
Figure 5.3: Lower Trapezius Strength Testing	72
Figure 5.4: Scapular Muscle Endurance Test	72
Figure 5.5: Data Collection Procedure Example of One Patient	75
Figure 5.6: Between Groups Marginal Mean Scapular Muscle Strength Values and Standard Deviations.....	80
Figure 5.7: Marginal Mean Scapular Muscle Endurance Values and Standard Deviations	81

Figure 5.8: Within Groups Marginal Mean Scapular Muscle Strength Values and
Standard Deviations.....83

List of Appendices

Appendix A: Consent Form	100
Appendix B: Medical History and Demographics for Normal Controls.....	103
Appendix C: Medical History and Demographics for Patients.....	104
Appendix D: Survey of Upper Extremity Disability Quick (DASH).....	106
Appendix E: Patient Rated Tennis Elbow Evaluation.....	107
Appendix F: Explanation for Endurance Testing.....	109
Appendix G: Psychometric Properties for a 2lb Lifting Condition Performed with Ultrasound Imaging not Reported in Chapter 3	110
Appendix H: Between Day Trends for the Scapular Muscle Endurance Test in Healthy Individuals.....	111
Appendix I: Comparison of Mean Scapular Muscle Strength Values Recorded in Chapter 4 to Previously Reported Data	112
Appendix J: Comparison of Absolute Serratus Anterior Thickness Values Across Studies	113
Appendix K: Mean Heart Rates and Standard Deviations for LE patients and Controls During Data Collection.....	114
Appendix L: Comparison of Mean Scapular Muscle Strength Values Recorded for LE Patients in Chapter 5 to Previously Reported Data on Patients with Shoulder Pathology	115

Chapter 1 : Introduction

Background

Tennis elbow, lateral epicondylitis, lateral epicondylosis, and lateral epicondylalgia are all terms that have been used to describe pain in the region of the lateral epicondyle of the humerus.¹⁻² Early investigators believed that the pain experienced at the lateral epicondyle was a result of an acute inflammatory condition at the origin of the common wrist extensors.³ However, the absence of inflammatory cells during histological examination as well as evidence of wrist extensor tendon degeneration⁴⁻⁶ has also lead to the use of the term lateral epicondylosis. In addition to the involvement of the common wrist extensors, the lateral collateral ligament and radial nerve have also been identified as possible sources of lateral epicondylar pain.⁷⁻⁹ Because the pathoanatomic origin is largely unknown, it has been recently recommended to use a more general term, lateral epicondylalgia (LE), to describe the pain experienced in the region of the lateral epicondyle.²

While a high percentage of recreational tennis players develop the pathology,¹⁰ LE is a common disease with significant consequence in the working population. The prevalence of LE has also been reported as high as 12.2%.¹¹ Those reported to be most at risk include workers that sustain awkward postures and perform a high number of repetitive motions at the elbow or wrist. In addition workers that report high perceived physical exertion, body mass index greater than 25kg/m², and those with low social support are more at risk.¹¹⁻¹² Up to 5% of workers with LE will take at least 2 months of sick leave for the condition and 27% report severe limitations with activities of daily living,¹³ such as lifting bags or boxes.¹⁴

The activity and participatory restrictions associated with LE can be costly to treat. In a survey of patients with epicondylitis, 42.9% consulted a physician about the complaint,¹⁴ while the mean total cost for treating the patient could be as high as \$828 USD per patient.¹⁵ In addition, the average total direct cost claim in treating epicondylitis for an employer in Washington state from 1994 to 2002 was \$9, 723 USD.¹⁶ Most importantly, prolonged symptoms or relapse upon return to the offending activity are frequently observed,^{13, 17-20} potentially resulting in even higher costs to employers, secondary providers, and patients.

In general, conservative management is the most frequent approach among physicians.²¹ However, there is a lack of consistent scientific evidence across a spectrum of conservative treatment approaches for patients with LE. A systematic review, published in the *Lancet*, found corticosteroid injections were effective in pain management, but only for up to 8 weeks from the time of the injection.²² In addition, corticosteroids can cause weakening of the structure of the tendon, post injection pain, subcutaneous atrophy, and skin depigmentation with increased frequency of use.²²⁻²⁵ There is good evidence (grade of B according to the Centre of Evidence Based Medicine)²⁶ supporting the short term efficacy, up to 3months in pain relief, for physical rehabilitation as a treatment strategy.²⁷

Despite good short term evidence, the role rehabilitation plays in the management of LE remains elusive secondary to questions with long term management. First, modalities such as ultrasound, iontophoresis, and acupuncture have been shown to be effective in the short term (0-3 months) but no difference to placebo in the long term (greater than 6 months).²⁸ Second, other intervention studies have not collected outcome

data beyond discharge. For example manual therapy and exercise interventions targeted at the elbow and wrist have shown large effect sizes when comparing the intervention to control group but lack of follow up limits any firm conclusions for clinical practice. Finally, no additional benefit has been found for concurrent conservative treatment interventions. For example, a combination of exercise and corticosteroids was found to be no more effective than receiving corticosteroids injections alone.^{27, 29}

The lack of long term efficacy in the conservative management of LE is further confounded by the high recurrence rates. For example, a recent study reported between a 29% to 38% recurrence rate within one year of receiving conservative treatment management.²⁹ Finally, in the only study to follow up after two years of physiotherapy intervention, over half the patients reported pain and functional loss secondary to a relapse in LE symptoms.³⁰

High recurrence rates and the uncertainty of whether conservative management is having a positive effect on long term outcomes in patients with LE, suggests a component of the rehabilitation process is missing. The majority of the reported conservative treatment approaches involve localized treatment in the region of the lateral epicondyle. Interestingly, other investigators have recently begun to explore the occurrence of regional impairments in patients with LE. To that end, impairments of the cervical spine³¹⁻³³ and shoulder³⁴⁻³⁸ have been reported in patients with LE. These findings imply that the proximal upper quarter should be considered in the rehabilitation of patients with LE.

Recent research focusing on scapular muscular strength and endurance gives some indication that scapular muscles may need to be screened and treated in patients with LE. For example, diminished LT strength in female tennis players compared to

asymptomatic female tennis players has illustrated that there is potential relationship between scapula muscular function and LE.³⁹ In a healthy population, fatigue of the scapular stabilizers has been shown to produce kinematic alterations of the elbow in throwing athletes.⁴⁰ This study implies that scapular muscle fatigue could predispose individuals to injuries in the elbow region by altering elbow kinematics. Another investigator found that induced pain at the upper trapezius appears to produce an increase in wrist extensor EMG activity in healthy individuals.⁴¹ Clinically, overuse of the upper trapezius and underuse of the lower trapezius, could result in upper trapezius pain. Because upper trapezius pain can result in increased activity of the common wrist extensors, the clinically observed trapezius imbalance may be an indirect link to an overuse wrist extensor injury.

Although it appears scapular muscle strength and endurance has a potential influence on patients with LE, the conclusions that can be drawn from these studies are limited. First, knowledge of scapular muscle strength in patients with LE is limited to a population of female tennis players.³⁹ Because there is a high prevalence of LE in the working population,¹¹ and most studies report that males will develop the condition just as frequently as females,¹⁷ future studies should investigate scapular muscle strength in a more inclusive group of patients. Second, although the study by Hidetomo and others, implies that fatigued scapular muscles may contribute to elbow pathology,⁴⁰ no studies have directly investigated the influence of scapular muscle endurance on LE patients. Therefore, future studies are needed to describe both scapular muscle strength and endurance in a working population who develop LE.

There are a few clinical tools available to assess both scapular muscle strength and endurance. Manual muscles testing (MMT) and strength testing with a hand held dynamometer (HHD) are commonly used to assess scapular muscle strength in a clinical setting.⁴²⁻⁴³ The HHD is thought to be superior to MMT in quantifying strength because the HHD provides more precise and objective data. In regard to measuring scapular muscle endurance, two investigators have reported the time a subject can hold an isometric contraction to failure.⁴⁴⁻⁴⁵ Another author quantified serratus anterior endurance by recording the number of shoulder protraction repetitions with a known load in the supine position.⁴⁶ Because, repetitive shoulder motions are not a risk factor for developing LE,¹² the static endurance test may be a more appropriate endurance test for this population.

There are several limitations to the aforementioned clinical tools that can be addressed before designing a study to investigate scapular muscle measures in patients with LE. First, it is generally unknown whether differences in arm dominance plays a role in upper extremity strength.⁴⁷ Arm dominance may be a confounder when comparing scapular muscle measures in patients with LE to a non-involved limb or a healthy control. To the author's knowledge the influence of arm dominance on scapular muscle strength has never been determined.⁴⁸ Closely related to dominance, Turner and others found increased strength for all scapular muscles except the LT when comparing healthy individuals that reported a high amount of shoulder activity to those reporting low shoulder activity levels.⁴⁸ Given these results and assuming the dominant arm is used more than the non-dominant arm, one might hypothesize that the dominant arm would be stronger than the non-dominant arm for all muscles except the LT. A second limitation to

clinical scapular muscle tools is that the reliability of the aforementioned endurance tests has never been reported. Third, with clinical strength and endurance tests, it is difficult to completely isolate specific muscles.⁴⁹ The ability to isolate specific muscles is important for identifying specific impairments and therefore specific interventions for individual patients.

Rehabilitative Ultrasound Imaging (RUSI) may be a good alternative in the assessment of scapular muscle measures. RUSI has the ability to identify specific muscles, is objective, and is easy to use.⁵⁰⁻⁵¹ In addition, RUSI has the ability to detect change in muscle architecture without the application of high loads.⁵²⁻⁵³ More specific to scapular muscles, good reliability and validity has been established in the literature for measuring muscle thickness of the lower trapezius (LT).^{49,54}

The psychometric properties of using RUSI to measure scapular muscle thickness are largely unknown. Although methods for measuring thickness of the LT have been discussed, the serratus anterior (SA), another key scapular stabilizer⁵⁵, has never been investigated with ultrasound imaging. It is also unclear if measurements of muscle thickness of the LT and SA, using RUSI, are sensitive enough to detect differences between pathological and healthy individuals.⁵⁶ Before this question can be answered, the reliability and sensitivity of the instrument to detect changes in thickness from a healthy population should be investigated.

Problem

Lateral epicondylalgia is one of the most common upper extremity musculoskeletal pathologies. High recurrence rates and lack of long term efficacy of conservative treatment approaches have lead authors to investigate the prevalence of

regional secondary impairments in patients with LE. The literature suggests that the scapular muscle strength and endurance may be important components in the rehabilitation of this pathology. Before an intervention strategy is investigated, it is important to describe the clinical phenomenon.⁵⁷ Information obtained from a descriptive study would be valuable in determining the feasibility of a larger intervention study. If scapular muscle strength and endurance are important in the long term management of patients with LE, it is reasonable to postulate that patients presenting with LE have scapular muscle impairments. Currently, there is limited empirical evidence that directly supports or refutes this claim.

There are three considerations that should be addressed before scapular muscle strength and endurance is investigated in patients with LE. First it is unknown whether arm dominance plays a role in scapular muscle strength and endurance. Second, it is unknown whether the available scapular endurance tests can be performed reliably. Finally, because shoulder girdle muscles are known to work synergistically, it is difficult to isolate specific scapular muscles with clinical testing. The ability to isolate specific muscles is important for addressing specific muscle impairments during a plan of care. RUSI is a potentially useful tool for isolating specific scapular muscles but few studies have investigated its utility.

Purpose and Aims

The first purpose of this dissertation is to explore the reliability and sensitivity of RUSI for measuring muscle thickness of the LT and SA in healthy individuals. The second purpose is to determine the reliability and effect of limb dominance on measures of scapular muscle strength, endurance, and change in muscle thickness in healthy

individuals. The third and primary purpose of this project was to investigate scapular strength, endurance, and change in muscle thickness impairments in patients with LE.

Specific Aim 1: Determine the reliability and sensitivity of ultrasound imaging in assessing muscle thickness of the LT and SA. This aim will test two hypotheses 1) RUSI will demonstrate good to excellent within and between day reliability for measuring absolute muscle thickness of the LT and SA. 2) A significant increase in load on the shoulders will result in a significant increase in muscle thickness of the LT and SA as measured by RUSI. Healthy individuals will be recruited to obtain measurements of SA and LT thickness when the shoulder is resting and under a series of different loads. This study will provide insight into whether RUSI can detect changes in scapular muscle thickness in healthy individuals.

Specific Aim 2: Determine differences in scapular muscle strength, endurance, and change in muscle thickness between the dominant and non-dominant limbs. This aim will test two hypotheses 1) Scapular muscle strength, measured with a hand held dynamometer, and a posterior scapular muscle endurance tests will be reliably measured within the same day. 2) There will be significantly greater scapular strength, endurance, and change in muscle thickness for the dominant limb compared to the non-dominant limb for all measures except for LT strength and change in thickness of the LT. Healthy volunteers from the central Kentucky area will be recruited to investigate differences in scapular muscle strength and endurance between an individual's dominant and non-dominant upper limbs. This study may provide insight into whether arm dominance is a confounding factor when internally or externally comparing a patient's scapular muscle measures.

Specific Aim 3: Evaluate scapular muscle measures in patients with LE. This aim will test two hypotheses 1) There will be a statistical and clinically meaningful decrease in scapular muscle strength, endurance, and change in thickness of the LT and SA muscles when comparing patients with LE to healthy controls. 2) There will be no significant differences in scapular muscle strength, endurance, or thickness when comparing an LE patient's involved limb to uninvolved limbs. These hypotheses are based on the results of a similar study that found significantly less shoulder rotational strength when comparing LE patients to controls but no differences in strength when comparing the involved to uninvolved limbs.³⁶ To test our hypotheses, a series of scapular muscle tests will be conducted bilaterally on patients with LE and generally matched healthy controls. This study will provide insight into the importance of assessing scapular muscles in patients with LE.

Clinical Implications

These studies will provide valuable information to the utility of assessing scapular muscles. Evidence for reliable clinical scapular muscle measures will provide clinicians with a set of tools for assessing scapular muscle behavior in patients with more distal upper extremity pathologies. Given the resources, reliable methodology developed for assessing the LT and SA using RUSI could be used by a clinician to identify specific scapular impairments for any range of pathologies. In addition, ultrasound assessment could be used for patients with lifting restrictions in a variety of pathologies. The second study also will lend insight as to whether scapular muscles measures in patients with a unilateral impairment can be compared to uninvolved limbs in a clinical setting.

The final study will provide the clinician with evidence as to whether rehabilitation specialists should be screening and potentially treating scapular muscle impairments in patients with LE. Identifying scapular muscle impairments would support the need for future studies to investigate interventions targeting scapular muscles in patients with LE.

Operational Definitions

Lateral epicondylalgia – health condition categorized by either acute or chronic pain at the lateral epicondyle of the humerus. The term includes, but is not limited to, patients with an active inflammatory process or degenerative process at the common wrist extensor origin.²

Scapular muscle measures – a combination of scapular outcome measures including strength, endurance, and muscle thickness.

Strength – a recorded level of exerted isometric force measured in kilograms by a hand held dynamometer. The position of the test is dependent upon the targeted muscle group.

Endurance – the ability to sustain a prolonged force production.

Absolute muscle thickness – measure of muscle depth measured by ultrasound imaging in centimeters.

Change in muscle thickness – the contracted muscle thickness – resting muscle thickness.

Chronic – duration of symptoms are greater than 6 months.

Statistical significance – compared values of interest were considered different at $p \leq .05$ but the differences are not necessarily beyond the measurement error of the procedure used to collect the data.

Clinically Meaningful – the observed differences between two values exceeds the measurement error of the procedure used to collect the data.

Assumptions

It will be assumed that:

1. Subjects who meet the clinical inclusion criterion will have the condition of interest; LE.
2. Control subjects will be free of upper quarter pathologies within the last 6 months.
3. Subjects will give their best effort during data collection.
4. Patients with LE will understand the Patient Rated Tennis Elbow Evaluation (PRTEE) form and will provide answers that reflect their current level of pain and disability to the best of their ability.
5. Healthy subjects will not significantly alter their activity levels between days for the purposes of endurance reliability testing.

Delimitations

1. Subjects for the reliability testing will also be used as a healthy control group for comparison to patients with LE. The subjects will be generally matched to LE patients by age and gender.
2. Muscle thickness will not be evaluated on all subjects secondary to the limited availability of the ultrasound imaging unit.
3. Assessment will be performed by one physical therapist with eight years of clinical experience.
4. The primary investigator will not be blinded to arm dominance in healthy participants or the involved side in patients with LE.

Copyright © Joseph M. Day 2013

Chapter 2 : Review of the Literature

Introduction

The purpose of this literature review was to 1) discuss the efficacy of conservative treatment approaches for LE; 2) discuss the available literature most closely pertaining to the kinetic chain theory and scapular muscle strength and endurance in patients with LE; 3) discuss the current evidence in regards to clinical measures of scapular muscle strength, and endurance; and 4) discuss the available research on the utility of RUSI for measuring scapular muscle thickness.

Efficacy of Conservative Treatment Approaches for LE

Initially, a conservative approach is the standard of care for managing patients with LE.⁵⁸ The most common conservative treatment approaches include cortisone and botulinum injections as well as physical rehabilitation. Initially, conservative treatment of LE appears to be beneficial, but there is little evidence to support the effectiveness of conservative management after six months from discharge.⁵⁹

Injection therapy is a common conservative modality used by physicians in patients with LE. According to three systematic reviews, cortisone and botulinum injections are effective in reducing pain and disability scores but have not been found to be effective after 3 months.⁶⁰⁻⁶² In addition there is some evidence to support that cortisone injections result in a high recurrence rate and inherent steroidal side effects.^{17, 63}

There are over 40 physical therapy treatment techniques reported in the literature for treating LE, yet no one treatment has been proven to be most effective or demonstrate consistently good long term outcomes. A systematic review reported by Kohia and others concluded that there was marginal evidence for Cyriax physical

therapy, which includes deep transverse friction massage followed by passive elbow extension, and shockwave therapy in reducing pain scores.⁶⁴ In another systematic review, Borkholder and Hill found that splinting offers early positive outcomes in patients with LE, yet none of the studies included in the review reported follow up times greater than 4 weeks.⁶⁵ A meta-analysis on the effectiveness for conservative treatment approaches for LE concluded that there was good short term evidence (up to 3 months) for ultrasound, iontophoresis, and acupuncture but the treatment effects on pain and global improvement seem to diminish after 3 months.²⁷ Finally, a recent systematic review on electromodalities concluded that there was moderate evidence for using ultrasound and laser therapy for treating epicondylitis.²⁸ Therapeutic exercises directed at the wrist and elbow, mobilizations, and manipulations also show promise in the short term but lack empirical evidence for efficacy longer than 6 months post discharge. Isotonic and eccentric wrist exercises appear to be effective in reducing short term disability scores, but outcomes were limited to 6 months follow up.⁶⁶ In addition, a mobilization with movement technique directed at the elbow is beneficial in improving short term pain and functional scores.⁶⁷ Emerging evidence also supports cervical manipulation for improving short term outcomes in patients with LE. Three trials have reported on the coexistence of cervical joint dysfunction in patients with LE. There is promising evidence that treatment of these conditions improves disability and pain scores but only immediately after intervention.^{32-33, 68}

There are three plausible explanations for the lack of long term conservative evidence for the treatment of LE. First, if LE is a permanent local injury then evidence for long term effectiveness is expected to be poor. However, this is not likely the case

because LE is has been reported to be a self limiting condition for some patients within 1-2 years of onset.⁶⁹ Another explanation for lack of evidence in the long term management is that few studies with successful short term outcomes have investigated the benefits of therapy for longer than 3 months after discharge. This is a plausible explanation, however, for the few investigators that have followed the long term effects of rehabilitation techniques on LE, high recurrence rates and poor long term results are consistently reported.²⁹⁻³⁰ Finally, it has also been suggested that the lack of long term evidence and high recurrence rates may reflect that an important treatment component is being missed in conservative treatment strategies.⁵⁹ To that end, it has been suggested that clinicians should assess and treat scapular muscle imbalances present in individuals with LE.^{39, 70-71} The hypothesis that scapular muscles play a role in the assessment and long term management of LE is strongly supported by the kinetic chain theory.^{37, 72}

The Kinetic Chain Theory and Lateral Epicondylalgia

The Kinetic Chain Theory (KCT) proposes that during functional arm motions kinetic energy is transferred from proximal to more distal segments of the arm, providing an effective and efficient mode for distal function.⁷³⁻⁷⁴ The theory originated as a biomechanical model for increasing performance in throwing sports.⁷⁵ The model is proposed to describe the means by which an increase in distal velocity and force is achieved by initiating motion through the lower extremities and trunk.⁷⁶

The principles of this theory originate from basic physical laws. It is well known that the force output of a system is influenced by both the mass and acceleration of an object. To increase force output at a distal segment, proximal segments accelerate the entire system by transferring segmental velocity distally.⁷⁷

The transfer of kinetic energy along the upper extremity during functional tasks is supported by the feed forward mechanism. The feed forward mechanism is the observation that proximal muscle activation precedes distal function. It is well documented in the literature that a proximal to distal muscle activation pattern occurs during functional tasks. For example it is known that contraction of the trunk musculature and deep cervical flexors occurs before upper extremity movement.⁷⁸⁻⁸¹ Furthermore, during reaching tasks, shoulder activity occurs before activation of the extensor carpi radialis and flexor carpi radialis.⁸²⁻⁸³

There is also evidence that the proximal to distal muscle activation occurs in the upper extremity during functional tasks. Hirashima and others found a sequential muscle activation pattern from the scapular protractors to the shoulder, and then down to the elbow extensors in 9 healthy male throwing athletes.⁸⁴ In addition, during a reaching task, the scapulothoracic musculature activates during the first 5-15% of the arm movement cycle. To that end, the peak scapulothoracic muscle activation appears to be before onset of the anterior deltoid, biceps, and triceps musculature.⁸⁵

In further support of the KCT, another group of studies have shown that the shoulder may have an influence on hand function. According to Martelloni and others, both proximal shoulder musculature and distal forearm muscles are activated during reaching and grasping activities.⁸⁶ Three other studies have confirmed that grip strength is associated with the amplitude of shoulder muscle activation.⁸⁷⁻⁸⁹ In addition, with disuse of the hand, shoulder muscle activity decreases over time.⁹⁰ As it relates to the scapular muscles influence on hand function, Naider-Steinhart and Katz-Leurer found

that control of the upper trapezius muscle influenced the speed of hand writing tasks in healthy individuals.⁹¹

The KCT along with the above empirical evidence suggests that proximal musculature has an influence on distal function. If scapular musculature is an important component of the rehabilitation process with LE, it would be reasonable to assume then that current literature would also support the hypothesis that shoulder girdle musculature influences the elbow. Therefore, a search was conducted on the relationship between scapular muscle impairments and measures of performance at the elbow. In addition, the presence of shoulder girdle impairments in patients with LE was reviewed.

The scapula and elbow

There is limited evidence that scapular musculature and scapular kinematics effect elbow motion and pathology. Scapular muscle fatigue has been associated with altered kinematic motion at the elbow. Specifically, after fatiguing exercises targeting the scapular stabilizers in healthy individuals, there was an increase in overall elbow motion in the cocking phase and an increase in elbow velocity in the follow through phase of throwing. It was concluded that this alteration in elbow motion may contribute to elbow pathology.⁴⁰ Another study demonstrated the relationship between experimental pain in the upper trapezius and wrist extensor/flexor muscle activity. Specifically, the authors found that experimentally induced upper trapezius pain lead to a decrease in activity in the wrist extensors and a decrease in rest time of the wrist flexors during a computer task.⁴¹

Shoulder girdle impairments and lateral epicondylalgia

The findings from one cross sectional study directly supported the importance of scapular musculature in patients with LE. Lucado and others found significantly weaker lower trapezius muscles in a group of female tennis players with LE compared to a matched group of asymptomatic female tennis players. Although limited in its application to the general population of patients with LE, this study indirectly supports the hypothesis the scapular musculature potentially plays a role in the development of LE.

In close relationship to the scapula, a variety of shoulder impairments have been reported in patients with LE. A retrospective study has identified limitations in shoulder internal rotation active range of motion in a group of tennis players with LE. The authors proposed that the mechanism of injury may have been due to compensatory wrist flexion to accommodate for losses in internal rotation range of motion of the shoulder.³⁴ Furthermore, an epidemiological study has shown that frozen shoulder and LE occurred together 2 – 3 more times than what would be expected in the general population.⁹²

In a series of studies, Alizadehkhayat and others have investigated shoulder strength and endurance in patients with LE. In the first study, the authors found a significant decrease in isokinetic shoulder abduction and rotator cuff strength when comparing patients with LE to matched controls.³⁵ In a second study, strength and fatigue were assessed for select upper extremity muscles in patients with LE compared to the uninvolved side and also to controls. In this comparison, no differences were found in shoulder strength for the within groups comparison for the involved and uninvolved limb, however, shoulder abduction, internal rotation, and external rotation were significantly diminished when compared to matched controls. Additionally, there were no differences

in supraspinatus or infraspinatus fatigue when compared to controls or the uninvolved limb.³⁶ In the third study, a group of previously rehabilitated patients with LE demonstrated significant shoulder strength deficits when compared to controls. In this investigation only treatment was administered to the lateral elbow region. The authors found significant decreases in shoulder abduction, internal rotation, and external rotation strength for both the involved and uninvolved limbs when compared to controls. There were no significant differences in shoulder strength when comparing the involved to the uninvolved limb. This finding implies that patients with unilateral LE present with bilateral shoulder weakness even after successful short term rehabilitation. The finding that shoulder weakness did not improve after lateral elbow pain was resolved might suggest the persistent shoulder weakness is a contributing factor for the high recurrence rates found in patients with LE.³⁸

Kinetic Link Between Scapular Musculature and Lateral Epicondylalgia

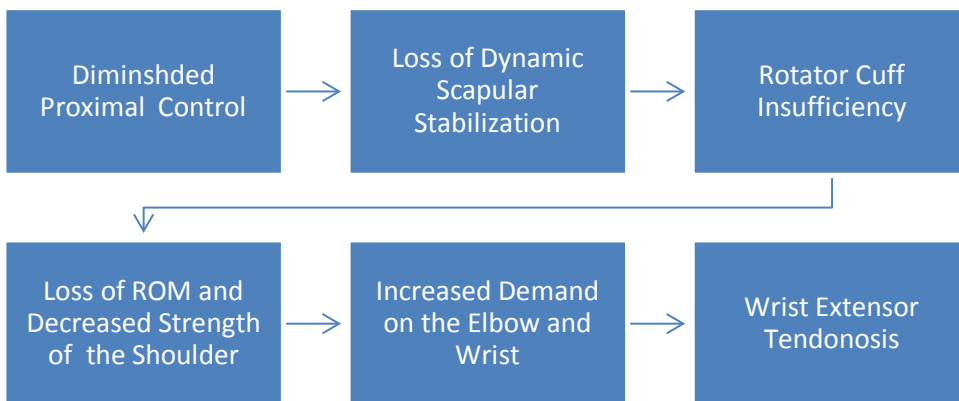
The kinetic chain theory provides a theoretical foundation for linking the importance of scapular musculature to muscle performance at the elbow. The author will first propose a mechanism, grounded in the kinetic chain theory, explaining how proximal muscle dysfunctions of the scapula could be linked to the development of a more distal pathology, LE. Second, the impact that scapular stabilization could have on outcomes and how this approach might be different to other treatment approaches already proposed in the treatment of LE will be discussed.

As noted earlier, the scapulothoracic and shoulder musculature appear to activate first during reaching activities implying that proximal stability occurs before a more distal functional task. A decrease in scapular control may occur secondary to peri-

scapular muscle imbalances. Peri-scapular muscle imbalance may result from, but is not limited to poor posture, cervical/thoracic joint dysfunction, or a combination of the two.⁹³⁻⁹⁶ For the proposed model, the author will assume that the proposed pathological pathway begins with poor upper quarter posture and, as a result, will effect scapular muscle strength and endurance (Figure 2.1).

After the scapula, the glenohumeral joint is the next link in the kinetic chain. There is good evidence to conclude that glenohumeral dysfunction such as rotator cuff pathology, can be caused by a decrease in scapular control.⁹⁷⁻¹⁰⁰ It is also known that rotator cuff pathology can cause gross weakness in the shoulder as well as decreased shoulder rotation range of motion.¹⁰¹⁻¹⁰² Therefore, it is possible that the aforementioned findings of diminished shoulder strength and range of motion could be a result of rotator cuff insufficiency.

Figure 2.1: Linking Scapular Muscle Dysfunction with Lateral Epicondylalgia



Scapular muscle weakness and rotator cuff insufficiency would likely cause a destabilized shoulder girdle. An inefficient and destabilized shoulder girdle, according to the kinetic chain theory, places more demand on the musculature of the elbow and wrist

to initiate energy transfer that is required for functional movement. This hypothesis is supported by a study by Pascarelli and Yu-Pin Hsu who collected objective findings on patients that present with a variety of distal upper quarter pathologies. The authors found that over 70% of those examined demonstrated postural deficits of the shoulder and signs and symptoms consistent with neurogenic thoracic outlet syndrome.¹⁰³

According to the proposed pathological pathway, LE might be expected to develop over time in tasks that require a high amount of wrist extensor activity. In support of the proposed model, the common wrist extensors are known to be active during typing activities,¹⁰⁴ gripping activities,¹⁰⁵ repetitive elbow flexion/extension activities,¹⁰⁶ and other recreational activities.¹⁰⁷ As such, similar repetitive motions of the hand, wrist, and elbow as well as recreational tennis are known to be risk factors for the development of LE.^{11, 103, 108-111}

Notwithstanding, it may be argued that the pathway that links LE and scapular muscle weakness begins at the elbow instead of the scapula. Tendonosis of the common wrist extensors could also trigger weakness and dysfunction of the scapular muscles. Pain of the common wrist extensors may cause the patient to use the upper extremity less and in a more guarded range of motion. Over time, disuse would result in decrease in shoulder active range of motion and weakness of the shoulder musculature. A hypomobile shoulder could generate a compensatory hypermobile scapula resulting in a decrease in dynamic scapular stability. However, the Alizadenkhayat studies imply that shoulder muscle weakness existed prior to the onset of LE because they found no differences in shoulder strength between the subject's involved and uninvolved limbs but

strength differences were significant between subjects with LE and matched controls.^{35-36,}

38

The proposed integrated model could have significant implications for long term results and prevention of LE along with other similar upper extremity musculoskeletal pathologies. Currently, the literature supports many different modalities that appear to provide some short term benefit for LE.¹¹² However, addressing diminished postural endurance of the upper quarter and in particular dynamic scapular stabilization has never been carefully examined and therefore a risk factor for developing LE is possibly being overlooked. The fact that scapular muscle measurements have not been carefully examined in patients with LE, may explain why there are many effective short term modalities for LE but no good evidence on long term benefits or prevention. In support of this argument, there is evidence that patients continue to experience upper extremity weakness and fatigue even after localized pain symptoms of LE have resolved. These findings suggest that an underlying contributor to LE, proximal weakness, has not been addressed.³⁸

Limitations

When interpreting the proposed model (Figure 2.1), there are several limitations that should be noted. First, the author is specifically referring to lateral epicondylalgia as an overuse injury of the common wrist extensors. To that end, it is important to clarify that the information presented does not necessarily reflect all pain that may develop at the lateral epicondyle. Other differential diagnoses like cervical radiculopathy, radial nerve entrapment, radial collateral ligament injuries, and radiocapitellar pathology are not necessarily included in this discussion. Second, it is the author's opinion, that treatment

of the scapula and shoulder would potentially be one facet of a multimodal treatment plan for LE. Therefore, direct intervention to the lateral epicondyle is still an important component of rehabilitation. Third, a large majority of the current literature in support of the kinetic chain theory is based on data from young adults who are athletes. This is important to consider because the mean age of patients presenting with LE is between 40 and 60 years old.¹¹³ Lastly, most of the data presented in the studies reviewed are electromyographic (EMG) and kinematic findings. Although these are widely accepted tools for measuring scapular and shoulder dysfunction, these tools are generally not available to clinicians. Therefore, this poses difficulty when attempting to clinically evaluate and assess scapular muscle dysfunction in patients with LE.

Future Studies

Future studies should expand on the limited evidence that scapular muscle dysfunction is present in patients with LE. More specifically, scapular muscle measurements should be investigated in a general working population of LE patients and compare results to the patient's uninvolved limb as well as to matched controls. Clinically attainable measures such as scapular strength and endurance should be collected so that assessment techniques can be replicated by practicing therapists. In addition, it may be important to identify specific scapular muscles that may be involved so that a more specific intervention may be employed.

The identification of scapular dysfunction in patients with LE is only a first step. If an association is determined, studies should investigate whether scapular muscle control is an effective intervention in a specific cohort of patients with LE and if this approach improves long term follow ups and recurrence rates. Finally, larger studies

could be needed to determine the efficacy of a postural /scapular control program in the prevention of LE in the workplace.

Summary

From this literature review, there is not enough information to determine if scapular muscle strength and endurance plays a role in the management of patients with LE; however, scapular muscle dysfunction is potentially an important kinetic link in rehabilitation of patients with LE. As a first step in determining the role that scapular muscle strength and endurance plays in patients with LE, descriptive research is needed to determine if patients with LE present with scapular muscle dysfunction.

Clinical Measures of Scapular Muscle Strength and Endurance

The purpose of scapular musculature is often described in terms of dynamic stabilization.¹¹⁴ Strength and endurance have been shown to be important in quantifying proximal stability in the lumbar spine.¹¹⁵ In addition, both strength and endurance measures are easily performed in the clinic. Therefore, for the purposes of this paper, scapular muscle stability will be measured in both strength and endurance. The middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA) muscles are of primary interest because of their known dynamic stabilizing characteristics.¹¹⁴

The most common clinical methods of assessing scapular muscle strength are manual muscle testing (MMT), isometric strength testing with a hand held dynamometer, and isokinetic testing. MMT is clinically friendly but highly subjected to user error and bias.¹¹⁶⁻¹¹⁷ Strength testing with a hand held dynamometer is a reliable measure of scapular muscle strength.⁴⁸ Compared to MMT, dynamometer testing is a more precise way of measuring strength, but its validity in isolating specific muscles is in question for

the MT and SA.⁴³ Isokinetic testing is also used as a clinical measure of muscle strength. Isokinetic testing has the ability to record strength measures at different speeds. More specifically, the Biodex has been shown to be a useful isokinetic tool for measuring velocity dependent retraction and protraction of the scapula.¹¹⁸⁻¹¹⁹ However, isokinetic testing is not widely available to clinicians because of the cost.

Given the above positive and negative attributes for clinically measuring scapular muscle strength, the author proposes that strength testing using the hand held dynamometer is the best option because it is more accessible than isokinetic testing but is more precise than a subjective grading scale of 1-5. Michener and others demonstrated a reliable technique for the MT, LT, and SA (ICC>.88) and MDCs ranging from 2.0kg (19.62 N) to 3.6kg (35.32 N) of force when using the hand held dynamometer.⁴³ The same technique appears to be sensitive enough to distinguish between patients with shoulder impingement syndrome and healthy individuals.¹²⁰ In addition, this technique for measuring scapular muscle strength could distinguish between specific occupations in healthy individuals.⁴⁵

Compared to strength testing, techniques for clinically measuring scapular muscle endurance are less defined in the literature. In general, endurance testing includes both repetitions to fatigue and time to fatigue during a sustained isometric contraction. The only study describing repetitions to failure in the assessment of scapular muscle endurance was conducted by Wang and others. Endurance of the SA was assessed by loading the patient with 15% MVIC in a supine punch position while the number of repetitions was recorded until failure. However, this methodology for assessing SA endurance has never been applied on a pathological population.⁴⁶

In comparison to the repetition to failure method, there is more empirical evidence for the sustained isometric contraction method. Edmondston and others assessed scapular muscle endurance with a sustained external rotation isometric contraction while the shoulders were flexed to 90° with moderate reliability (ICC = .67) in patients with postural neck pain.¹²¹ Another group of studies investigated SA endurance in a prone plank position while a prone sustained isometric hold at 90° and 120° shoulder abduction was used to assess the MT and LT respectively.⁴⁴⁻⁴⁵ The sustained isometric endurance tests described by Tate and others appears to be sensitive to changes in athletes, indicating that there is a potential to distinguish between pathology and controls in an older population with more distal symptoms.⁴⁴

For the purposes of measuring scapular muscle endurance specifically in patients with LE, time to fatigue holding an isometric contraction may be more appropriate than the repetition to failure endurance test. Because there are no known risk factors for repetitive shoulder movement in the development of LE, repetitions to failure may not be the most appropriate for the LE population. Alternatively, because repetitive elbow, wrist, and hand movements are risk factors for developing LE; it would be reasonable to hypothesize that there may be a deficiency in the static stabilization of the scapular muscles while the distal kinetic chain is moving. Anecdotally, a sustained isometric endurance test may more closely represent the static stabilizing attributes of the scapular muscles.

One limitation of using a sustained isometric endurance test is that the test may be influenced by the development of muscle ischemia and not necessarily muscle fatigue. Intramuscular tissue pressure (MTP) increases during sustained isometric contractions

and MTP is known to interfere with muscular blood flow.¹²²⁻¹²³ More specifically, the impeded blood flow is thought to occur as a result of increased MTP especially around deeper venous structures of the muscles.¹²⁴ The impeded blood flow could result in muscle ischemia thus altering muscle performance.¹²⁵⁻¹²⁶ With diminished oxygen delivery, an acceleration of the metabolic process will occur and accelerate muscle fatigue.

It has been demonstrated that isometric fatigue tasks of the abdominals and lumbar extensors can improve overtime with training.¹²⁷⁻¹²⁸ At this time it is unknown whether the improvement seen in a timed sustained isometric fatigue test is secondary to a building tolerance of the ischemic process, alteration of the subject's perception of fatigue, or whether the improvement is a result of an improvement in the aerobic efficiency of the muscle. Regardless of the mechanism, the author proposes that the test has relevance to testing the hypothesis that LE patients have a diminished ability to maintain isometric stabilization of the scapula during a distal upper extremity task.

Ultrasound Imaging in the Assessment of scapular musculature

One of the limitations with clinical measures of strength and endurance is that it is difficult to isolate specific muscles.⁴³ The ability to isolate specific musculature has implications for treatment as treatment targeting more specific impairments is thought to be important in the treatment and prevention of disability.¹²⁹ In addition, in the early phases of rehabilitation, a patient's ability to tolerate manual resistance is often limited by pain and post-operative precautions.¹³⁰

Rehabilitative ultrasound imaging (RUSI) is potentially a good clinical alternative for assessing scapular musculature. Unlike current clinical measures, RUSI has the ability

to detect changes in a specific muscle's architecture without the application of high force on the shoulder.^{52-53,56} Second, RUSI is easy to interpret and is noninvasive.⁵⁰⁻⁵¹ Third, RUSI can provide objective measures of changes in muscle dimensions that are both reliable and valid.¹³¹⁻¹³³ Finally, with specific training techniques, RUSI has been shown to be sensitive enough to detect changes in muscle dimensions after a period of 13 weeks.¹³⁴

The most common measures of muscle architecture used by RUSI are muscle thickness,¹³⁵⁻¹³⁶ cross sectional area,¹³⁷⁻¹³⁸ volume,¹³⁹ and pennation angles¹⁴⁰ in a variety of muscles. A muscle's ability to generate force is closely related to its cross sectional area (CSA). However, RUSI is limited in its ability to capture CSA and volume of a large muscle. In addition, measuring pennation angles can be cumbersome and thus is not clinically friendly. Alternatively, muscle thickness can be measured quickly and thus appears to be clinically viable. To that end, thickness of the quadriceps, as measured by RUSI, has also been shown to be associated with strength.¹³³

To date, no studies have investigated muscle architecture of the SA using RUSI but there have been a series of studies investigating thickness of the LT. Measuring LT thickness in a resting prone position has been shown to be both a reliable and valid measure of muscle thickness.^{49,54} RUSI has also been used to assess change in lower trapezius thickness in patients with mild shoulder impingement. Although no difference in thickness between patients and controls could be detected, O'Sullivan and others acknowledged limitations to their study. One suggestion made for future studies was to assess muscle thickness of the LT in a functional position.⁵⁶

Before RUSI is used in assessing the scapular muscles in pathological individuals, psychometric properties should be further investigated in a healthy population. Research is needed to establish the within and between day reliability for measuring LT and SA muscle thickness on healthy individuals in a functional position. In measuring muscle thickness with RUSI, an assumption is made that an increase in muscle thickness is correlated with increased strength. Clinically, strength is measured by torque on the targeted muscle. However, the relationship between thickness increases of the LT and SA as measured by RUSI and increased torque has never been investigated.

Chapter 3 : Thickness of the Lower Trapezius and Serratus Anterior Using Ultrasound Imaging During a Repeated Arm Lifting Task

Introduction

The importance of the peri-scapular stabilizers on both shoulder pain and function has been established by EMG and motion analysis studies.⁹⁸⁻¹⁰⁰ As a result, neuromuscular re-education and strengthening are recommended for treating peri-scapular muscle impairments associated with shoulder pathologies.¹⁴¹⁻¹⁴² 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.⁵⁵ 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 serratus anterior along with other scapular muscles are difficult to isolate during manual muscle testing.^{43, 116-117} In the early phases of rehabilitation, a patient's ability to tolerate manual resistance is often limited by pain and post-operative precautions.¹³⁰ In addition, the accuracy of manual muscle testing is limited by tester strength.^{130, 143}

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.^{52-53, 56} RUSI is easy to interpret and noninvasive.⁵⁰⁻⁵¹ 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.^{131-133, 144} 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.^{133, 145-146}

Measuring LT thickness in a resting prone position has been established as a reliable technique.^{49, 54} However, the results of a recent study suggests 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.⁵⁶ 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 its anatomical accessibility¹⁴⁷ and lower SA activity is thought to play more of a role in shoulder joint stability compared to the upper fibers of the SA.¹⁴⁸

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 RUSI's 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.

Methods

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 their 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.

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.¹⁴⁹ 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.

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 transducer placement.⁴⁹ Good agreement for measuring resting muscle thickness at a similar location has been found with MRI.⁵⁴

For the SA, a mark was placed between the pectoralis major and the latissimus dorsi on a rib angle.^{147, 150} The rib chosen was located at the level of the inferior tip of the scapula.

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). This was repeated 3 times for 5 seconds with a 15 second 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 Brightness (B) mode, a 40mm 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 may increase with inspiration, the authors captured all images for the SA after expiration. An on-screen caliper was used to obtain the absolute thickness of the LT and SA.

Next, subjects were asked to lift a series of 10 external loads with their dominant 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 (1lb, 2lbs, 3lbs, 4lbs, 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 (Figure 3.1

and 3.2). This position is known to produce high SA activity and moderate LT activity¹⁵¹. Each load was held for 2 seconds, and each lift was repeated to establish within day reliability. The subject rested for 30-60 seconds 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.

Figure 3.1: Resting Subject Position and Probe Placement for the Lower Trapezius



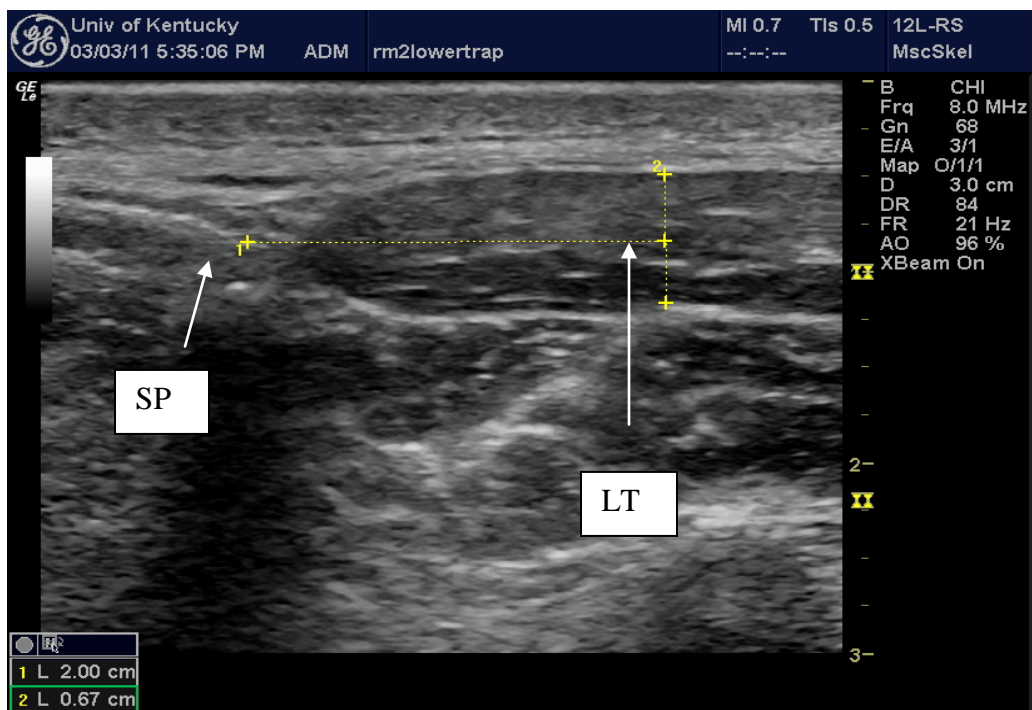
Figure 3.2: Resting Subject Position and Probe Placement for the Serratus Anterior



Data Organization:

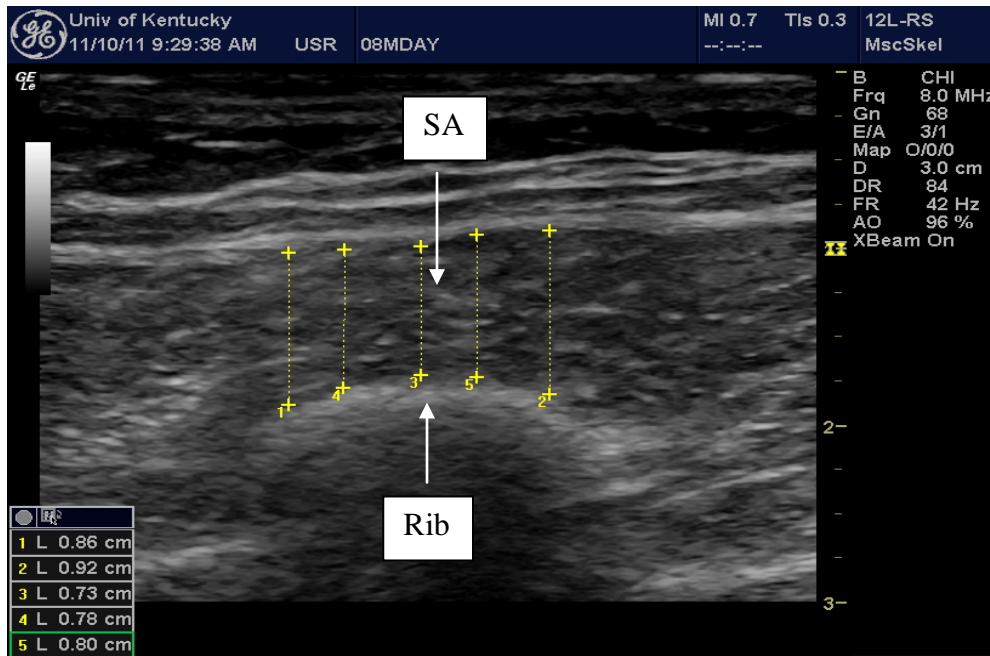
Linear measurements of the LT thickness were made 2cm from the spinous process⁴⁹ (Figure 3.3). Linear measurements of the SA were made from the border of the rib up to the inside edge of the muscle border. The average of 5 thickness measures, spanning the width of the rib, was used for analysis (Figure 3.4).

Figure 3.3: 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 2cm laterally. The vertical perforated yellow line was drawn between the two facial borders of the LT 2cm from the SP and represents LT thickness

Figure 3.4: 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.

Torque values for each lift were calculated with the following equation:

- Arm mass (N) = ((body weight in lbs) * .056)¹⁵²*4.48
- Arm Torque (Nm) = Arm mass (N) * ((length of arm in m)*.55)¹⁵²
- 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, a repeated measures analysis of variance (ANOVA) was used 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 75% MVIC represented our highest and lowest torque values respectively.

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. Intraclass correlation coefficients (ICCs) and their 95% confidence intervals were used to determine the level of agreement both within and between days for absolute thickness calculations. The standard errors of the mean 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.

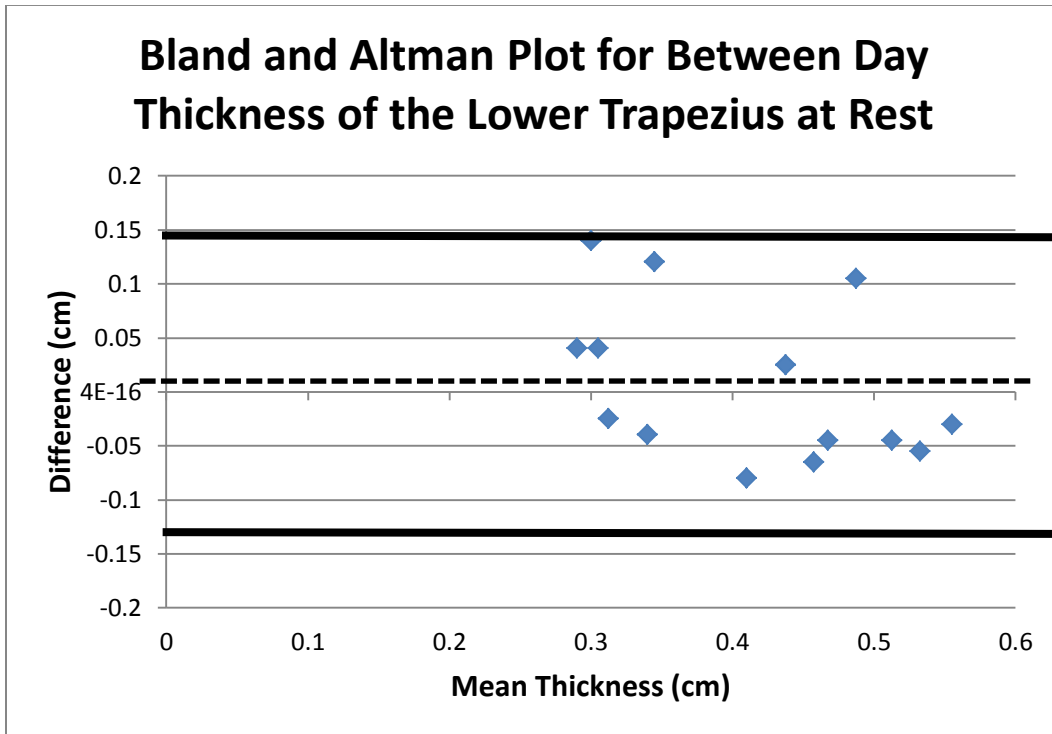
Separate repeated measure ANOVAs for each muscle compared the average absolute muscle thickness for three selected conditions for testing on day 2. Finally, post hoc Bonferroni analyses were run to determine individual differences in average absolute muscle thickness. Statistical Analysis was performed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

Results

LT and SA within and between day ICCs, SEM, and MDC for the 3 lifting conditions are presented in tables 3.1 and 3.2, respectively. The intra-session reliability ($ICC > 0.94$) was excellent and the inter-session reliability ($ICC > 0.86$) 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 .006cm with no

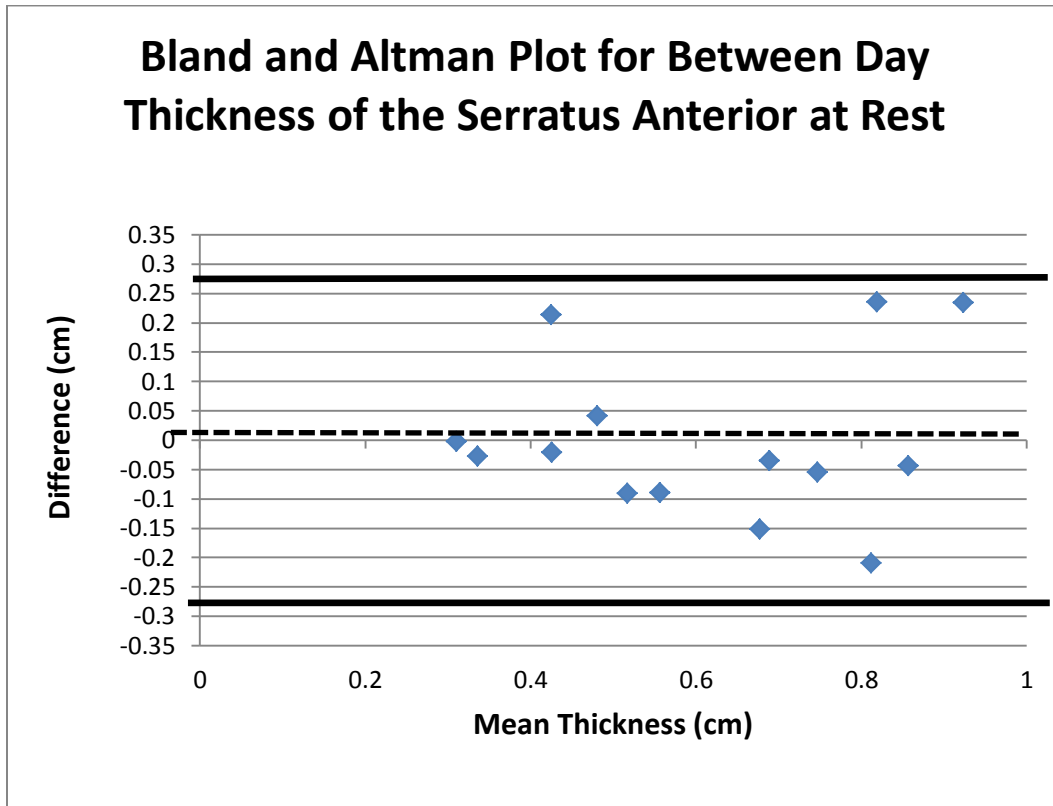
outliers. The standard deviation of the difference was .07cm, therefore the 95% limits of agreement were -.134 cm to .146. (Figure 3.5) Bland and Altman plot for the SA revealed a mean difference was < .000 cm and there were no outliers. The standard deviation of the difference was .138cm, therefore the 95% limits of agreement were -.28 cm to .28 cm. (Figure 3.6)

Figure 3.5: Bland and Altman Lower Trapezius



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.

Figure 3.6: Bland and Altman Serratus Anterior



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.

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 3.3) and SA (Table 3.4)

Table 3.1: Lower Trapezius Thickness Within and Between Day Reliability

Condition	Mean Thickness (cm)		ICC (95% CI)	SEM (cm)	MDC ⁹⁵ (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; MDC⁹⁵ = minimal detectable change with 95% boundary limit. Conditions refer to the subject at rest, subject lifting the arm at 90° scaption, and subject lifting a weight equivalent to 75% MVIC

Table 3.2: Serratus Anterior Thickness Within and Between Day Reliability

Condition	Mean Thickness (cm)		ICC (95% CI)	SEM (cm)	MDC ⁹⁵ (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; MDC⁹⁵ = minimal detectable change with 95% boundary limit. Conditions refer to the subject at rest, subject lifting the arm at 90° scaption, and subject lifting a weight equivalent to 75% MVIC

Table 3.3: 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 3.4: 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.

Discussion:

This was the first study to measure absolute SA thickness using RUSI and to demonstrate good within and between day reliability. We were also able to demonstrate good within and between day reliability of the LT in a functional sitting position, which is comparable to previous research.⁴⁹ Additionally, it was determined that external loads placed on the shoulder resulted in increased absolute thickness of the SA and LT as measured by RUSI.

Although there was generally good agreement, some of the between day ICCs had wide 95% confidence intervals (CI), 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.¹⁵³ 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. It was found that 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.¹⁴⁰ 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.¹⁵⁴ 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.¹⁵⁵ In contrast, other studies report high correlations between measures of muscle thickness and torque.^{145,156} 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.¹⁵⁷

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.¹⁵⁸ It is often recommended that researchers use normalized values because muscle thickness is known to be influenced by gender and body mass index.¹⁵⁹⁻¹⁶⁰ 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 measurements of muscle thickness of only the lower fibers of the SA were obtained.

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.

Chapter 4 : A Comparison of Dominant and Non-dominant Scapular Muscle Strength, Endurance, and Change in Muscle Thickness

Introduction

Alterations in scapular kinematics, muscle activity, and muscle strength have been associated with a number of upper extremity pathologies.^{39, 98-100, 120, 161-162} In addition, upper extremity functional activities like hand writing, feeding, grooming, reaching overhead, and throwing appear to require scapular muscle activation.^{40, 91, 163} Therefore, a thorough assessment of scapular muscle parameters is potentially important in treating associated impairments and restoring function of the upper extremity.

There have been many reported techniques for assessing scapular muscle parameters including evaluation of scapular kinematics,^{97, 164} scapular muscle electromyography (EMG),^{55, 165-166} scapular muscle strength testing with a hand held dynamometer (HHD),^{43-44, 48} and sustained isometric scapular muscle endurance testing.⁴⁴⁻⁴⁵ Clinically, tools for measuring scapular kinematics and EMG activity are time intensive and expensive, whereas measures of scapular muscle strength and endurance may be more easily performed by clinicians. In addition to strength and endurance testing, muscle thickness, measured by RUSI, has been used as an indirect measure of muscle strength^{133, 145-146} and muscle activity.¹⁴⁰ Although the clinical accessibility of RUSI is limited secondary to expense, RUSI is easy to operate, the results can be interpreted quickly for both researchers and clinicians, and has the ability to isolate specific scapular muscles.¹⁵⁸ The isolation of specific muscle impairments may be important for improving the effectiveness and efficiency of assessment and treatment interventions.¹²⁹

In the literature, scapular muscle strength, endurance, and muscle thickness are typically assessed in the population of interest and then compared to a matched control group.^{39, 45, 56, 120} However, clinicians often compare values obtained on a patient's involved limb to the uninvolved limb, thus making the assumption that there is symmetry between sides in healthy individuals. To that end, empirical evidence suggests that arm dominance might be a confounding factor when making an involved to uninvolved upper extremity strength comparison in patients. The dominant upper extremity has been found to be stronger during grip and elbow strength testing in a healthy population.¹⁶⁷⁻¹⁶⁹ More closely related to the scapula, multiple studies have found that arm dominance does not affect shoulder strength or strength ratios in several planes of motion.^{47, 170-171} Alternatively, two studies found increased shoulder external-internal rotation isokinetic strength ratios in the dominant arm.¹⁷²⁻¹⁷³ Although the literature is inconsistent, it cannot be assumed that arm dominance does not influence limb to limb comparisons in patients.

Scapular muscle strength has been shown to be influenced by activity level of the individual. Individuals with increased overhead activity levels demonstrated increased UT, SA, and MT strength compared to individual who rated themselves as less active. The only exception to this difference was the LT as the strength was equal between both groups.⁴⁸ It is reasonable to assume that the dominant limb is more frequently used in daily activities compared to the non-dominant limb, therefore this data suggests there may be increased UT, SA, and MT strength in the dominant limb compared to the non-dominant limb. However, no studies have directly investigated the effects of arm dominance on scapular muscle strength or endurance in healthy individuals..⁴⁸

The purpose of this study was to investigate the effect of arm dominance on scapular muscle strength, measured with a HHD, and scapular muscle endurance in healthy individuals. Secondly, the effect of arm dominance on change in scapular muscle thickness, measured by RUSI, will be examined. The researchers hypothesize that healthy individuals will demonstrate a significant increase in their dominant muscle strength for their SA, MT, and UT but no difference for the LT compared to the non-dominant arm. The authors hypothesize that the dominant arm will demonstrate increased endurance times compared to the non-dominant arm. Finally, we hypothesize that change in thickness for the SA will be greater on the dominant limb but no differences in dominance for LT change in thickness will be demonstrated.

Methods

Experimental Approach to the Problem:

A cross sectional study design was used to investigate the difference in scapular muscle strength between the dominant and non-dominant limbs in healthy individuals. More specifically, a HHD was used to investigate strength of the UT, LT, MT, and SA muscles using previously established methods that were found to be reliable.⁴³

In addition to acting as mobilizers, scapular muscles are thought to act as stabilizers.¹¹⁴ Therefore a static endurance test was also chosen as an assessment for static stabilization. Little has been published on assessing scapular muscle endurance, however, a common method to assess stabilizing musculature in the lumbar spine is a sustained isometric time to fatigue task.¹²⁷⁻¹²⁸ For the purpose of this study, a sustained isometric hold in the prone position with the arm abducted to 135° was chosen because this position is known to activate a variety of scapular muscles.^{151 165, 174-175}

As a third component to assessing the scapular musculature, RUSI was utilized to assess change in thickness of the LT and SA. RUSI will allow a specific isolated look at the contractile behavior of the LT and SA. The LT and SA were chosen because these two muscles control the scapula in several functional arm movements.⁵⁵

There are limitations to using the above instrumentation for assessing scapular musculature. First, validity has not been established for measuring MT/SA strength with a HHD or for measuring scapular muscle endurance in a prone position with the arm abducted to 135°. Second, from our findings in Chapter 3, RUSI may not be sensitive enough to distinguish between different levels of contractility when measuring thickness of a scapular muscle. Nonetheless, using these procedures and instrumentation, we can obtain a reasonable clinical assessment of a subjects scapular muscle behavior.

Subjects:

The sample of convenience consisted of 32 healthy volunteers (mean age = 44.4 ±9.78 years and mean BMI = 24.86 ±4.12 kg/m²) from the Central KY area. To be included in the study, subjects had to be between the ages of 30 and 65 and demonstrate the ability to tolerate and maintain the instructed test positions. (This age range was chosen because the methodology used for scapular muscle strength assessment was replicated from a previous study that included patients with a mean age of 43 years.⁴³) Subjects were excluded from the study if they reported: current or history of (less than 6 months) upper quarter musculoskeletal condition, had surgery in the last 6 months on the trunk or upper quarter, or reported a disability scores of greater than 10% as measured by the Quick version of the Disability of the Arm, Shoulder, and Hand (Quick DASH)

questionnaire .¹⁷⁶ All subjects read and signed an approved consent form by the University of Kentucky's Institutional Review Board.

Procedure

All participants completed a demographic questionnaire (Appendix B) which included shoulder activity levels (SAL)¹⁷⁷ and occupational physical demand level as measured by the Dictionary of Occupational Titles.¹⁷⁸ The SAL questionnaire has been shown to be a reliable and valid tool for assessing self reported activity levels.¹⁷⁷ Before the first dependent variable was measured, a baseline resting heart rate was obtained. A 5 minute rest period was given to the patients after each group of dependent variables were measured to allow time for recovery.¹⁷⁹⁻¹⁸⁰ Heart rate was measured immediately after data collection on each dependent variable group and then after the allotted 5 minute rest to ensure the patient had recovered to baseline values. Extra rest was given if the patient did not return to baseline values.

The order for scapular muscle measurements was randomized (thickness measures with RUSI, HHD testing, and endurance testing). The order within each scapular test (targeted muscle – UT, MT, LT, and SA) and the first limb tested (dominant versus non-dominant) was also randomized using Microsoft Excel 2007. For the purpose of calculating intra-rater reliability for the endurance task, some subjects agreed to return on a different day so that a second measure of endurance could be collected.

1. *Hand Held Dynamometer Manual Muscle Testing.* A Lafayette Microfet HHD was used to record force production of the patient. The procedure used to measure scapular muscle strength was followed from a previous study that reported good between day intra rater reliability for scapular dynamometer strength

measurements (ICCs .75 to .97).^{43, 181} Three maximum voluntary contractions (MVCs) for both the dominant and non-dominant sides were recorded. The investigator instructed the patient to push into the dynamometer with their maximum effort, holding for a 5 second duration. Subjects were instructed to slowly build up their force production to their maximum force before the end of the 5 seconds. The MVC was recorded by the assessor. An attempt was made to isolate the following muscles.

- Upper Trapezius - While the patient was in a seated position, the dynamometer was placed on top of the scapula. The patient was asked to elevate his/her shoulder against resistance as shown in Figure 4.1.⁴³
- Serratus Anterior – The patient was positioned supine with the shoulder and elbow flexed to 90°. The dynamometer was placed on the olecranon of the elbow and resistance was given along the humeral axis. The therapist positioned themselves as shown in Figure 4.2.⁴³
- Middle Trapezius – The patient was positioned prone with the elbow extended and shoulder held to 90° abduction. The dynamometer was placed on the spine of the scapula, in between the acromion and the medial superior border of the scapula. The subject was instructed to lift his/her arm upward, while resistance with the dynamometer was being applied in the lateral direction. The assessor positioned themselves as shown in Figure 4.3.⁴³
- Lower Trapezius - Subject was positioned prone with arm extended and shoulder held to 135° of abduction. The dynamometer was placed

in the middle line of the scapula, in between the acromion and the medial superior border of the scapula. While the patient lifted his/her arm upward, resistance with the dynamometer was applied in the lateral and superior direction. The assessor positioned themselves as shown in Figure 4.4.⁴³

2. *Scapular Muscle Endurance Testing*

Lying prone, the subject's shoulder was passively positioned to 135° of shoulder abduction with arm parallel to the trunk. A load representing 1% of body weight (rounded to nearest .5lbs) was strapped just superior to the elbow. A target, comprised of a vise grip (QUICK-GRIP®) attached to a free standing PCV pipe was positioned (Figure 4.5) at a height parallel to the trunk and at 135° of shoulder abduction. The subject was then asked to elevate and hold their arm to the established level for as long possible. The test was terminated when the subject voluntarily lowered their upper extremity or if the subject's distal radius was no longer contacting the level.⁴⁴⁻⁴⁵

Figure 4.1: Upper Trapezius Strength Testing



Figure 4.3: Middle Trapezius Strength Testing



Figure 4.2: Serratus Anterior Strength Testing



Figure 4.4: Lower Trapezius Strength Testing



Figure 4.5: Scapular Muscle Endurance Test



3. *Change in muscle thickness of the LT and SA using UI*

Subjects were seated comfortably on a chair without a back. A neutral spine posture was established by instructing the subject to sit upright and then slump three times. After the third movement, the researcher asked the patient to rest comfortably between the 2 motions.¹⁴⁹ The subjects were then asked to place their forearm on an adjustable table that was elevated to 85° in shoulder elevation and 45° shoulder horizontal abduction. Horizontal abduction was maintained throughout testing by placing a mark for arm position which was monitored continuously by the researcher.

A felt tip mark was placed at the level of the thoracic spine that coincided with the inferior angle of the scapula so that the ultrasound transducer could be placed in a consistent position for all measures.⁴⁹ Additionally a mark was placed on the lateral torso at the level of the inferior angle between the pectoralis major and the latissimus dorsi indicating the location of the serratus anterior.¹⁵⁰

Computerized ultrasonography (General Electric LOGIQ e 2008) was used by the primary investigator to produce a cross sectional image of the LT and SA at rest and during arm lifting. In B mode, a 40mm 8-MHz linear transducer was placed transversely over the mark previously made to identify the LT and vertically along the mark used to identify the SA. An on-screen caliper was used at a later time to obtain the absolute thickness of the LT and SA in resting and during contraction.

A 5lb weight was strapped around each participant proximal to the elbow. A 5lb weight strapped above the elbow was determined to be equivalent in torque to lifting a 2lb weight placed in the hand. Previously collected pilot data indicated that a significant increase in muscle thickness, for both the LT and SA consistently occurred when a healthy subject lifted a 2lb weight in the same position. First, an image was taken with the muscle in a resting state. Second, the subject was asked to elevate their arm with the elbow extended to 0° , shoulders horizontally adducted to 45° from the frontal plane and shoulder flexion to 90° . This position is known to produce high SA activity and moderate LT activity.¹⁵¹ The position was then held for approximately 2 seconds to allow an ultrasound images to be taken. A second resting and lifting image was taken for the same arm and muscle using the same procedure. The same procedure used on the first muscle was then repeated for the second muscle on the ipsilateral side. The entire procedure was then repeated for the other limb for both muscles.

Linear measurements of the LT thickness were made 2cm from the spinous process landmark.⁴⁹ Linear measurements of the SA were made from the inside

border of the rib up to the inside edge of the muscle border. The rib served as the on-screen anatomical reference. The average of 5 thickness measures, spanning the width of the rib, was used for analysis. Muscle thickness was measured twice for the lower trapezius as recommended by previous investigators.¹⁵³

Statistical Analyses:

Reliability: Analysis was performed using Statistical Program for the Social Sciences (SPSS) version 20. Intraclass correlation coefficients (ICCs) along with their 95% confidence intervals were used to compare the test retest reliability for all strength measures and endurance for both the dominant and non-dominant limb. (ICCs for LT and SA muscle thickness were previously reported in Chapter 3.) ICCs for strength were calculated within day, whereas endurance ICCs were between day. The standard error of the measure¹⁸² and minimal detectable change scores (MDC) were also calculated.

Scapular Muscle Measures in Dominant and Non-dominant Limbs: It was determined that a sample size of 32 subjects would provide 91% power to detect a minimal difference of 3.6 kg (35.32 N) assuming a common standard deviation of 6.0 kg (58.86 N) with an alpha value of .05. The minimal difference and standard deviation values were chosen from a previous study reporting SA HHD force values.⁴³

As part of our primary analysis, separate paired t tests were used to assess the difference in strength between the dominant and non-dominant limbs for the UT, SA, MT, and LT. The mean values used to compare sides were the average of the 3 trials taken for each muscle. Separate paired t tests were also used to assess the differences in endurance times between the dominant and non-dominant limbs. The level of significance was set *a priori* at $p < .05$

To test our secondary hypotheses, separate 2 way repeated measures ANOVAs were used to investigate the differences in change in muscle thickness of the LT and SA between subject's dominant and non-dominant limbs. The within subjects groups were condition (rest and contraction) and limb (dominant and non-dominant) A p value of .05 was set *a priori*. In the case of an interaction between group and limb, a least significant difference (LSD) post hoc analysis was performed. If no significant interaction was present, the model was run again without the interaction so that the main effects could be interpreted. Two of the 32 subjects included in the study did not undergo a RUSI examination secondary to time constraints. Therefore, 30 subjects (14 male, 16 female) were included in the RUSI analysis for both the LT and SA.

Results:

Descriptive analysis with means and standard deviations are provided in Table 4.1.

Reliability

Within day ICCs, SEM, and MDC for each of the hand held dynamometer strength tests are presented in Table 4.2. The intra-session reliabilities ($ICC > 0.85$) were good for all muscles being tested with the HHD. Between day ICCs, SEM, and MDC for the endurance test are presented in Table 4.3. The inter-session reliabilities ($ICC = 0.91$) were excellent for both limbs.

Dominant to Non-dominant Comparisons

There was a statistically significant increase in average peak force values on the dominant side for the UT ($p = .000$) and SA ($p = .052$) when compared to the non-dominant limb. However, the differences in average peak force values between the dominant and non-dominant limbs were not beyond the MDC_{90} reported in Table 4.2.

There were no statistically significant differences in LT ($p = .759$) or MT ($p = .08$) peak force values when comparing the dominant to non-dominant limbs (Figure 1).

For our endurance measures, there was a statistically significant increase in timed endurance ($p = .015$) for the dominant limb (mean = 87.41 ± 34.38 s) compared to the non-dominant limb (mean = 78.53 ± 36.38 s). Similar to peak force value results, the average difference between limbs was not beyond measurement error. For our RUSI outcomes, the 2 way interactions between condition and dominance were not significant for the LT ($p = .479$) or SA ($p = .986$). As expected, there was a main effect for condition for both the LT and SA ($p < .001$) indicating there was a significant increase in muscle thickness from rest to contraction regardless of arm dominance. There was also a main effect for dominance of the LT ($p = .001$) indicating that regardless of whether the muscle was resting or contracting, the LT was thicker for the dominant limb ($.55 \pm .17$ cm) compared to the non-dominant limb ($.48$ cm $\pm .19$ cm).

Table 4.1: Subject Demographics

Item	Subgroup	N	Percentage (%)
Gender	Male	15/32	46.9
	Female	17/32	53.1
Dominant Side	Right	31/32	96.9
	Left	1/32	3.1
Physical Demand Level	Sedentary	14/32	43.8
	Light	9/32	28.1
	Medium	8/32	25.0
	Heavy	1/32	3.1
Shoulder Activity Level	Low	15/32	47
	High	17/32	53

Shoulder Activity Level scores are based on a self reported questionnaire with a total possible score of 25. Low scores indicate low activity and high scores indicate high activity. Those who scored 0 – 12 were placed in the low subgroup and those scoring 13-25 were placed in the high subgroup

Table 4.2: Within Day Reliability for Hand Held Dynamometer Scapular Muscle Tests

Muscle	Force (N)			ICC (95% CI)	SEM (N)	MDC ₉₀ (N)
	Measure 1	Measure 2	Measure 3			
Upper Trapezius						
Dominant	238.77(61.60)	232.30(59.74)	232.69(64.45)	.96 (.94, .98)	10.59	24.62
Non-dominant	219.25(54.64)	211.50(52.78)	215.53(52.68)	.94 (.89,.97)	12.75	29.72
Middle Trapezius						
Dominant	151.66(28.94)	155.49(30.41)	155.68(30.90)	.93 (.88, .96)	7.75	18.15
Non-dominant	148.82(26.88)	146.17(29.82)	149.11(30.71)	.88 (.80, .93)	9.71	22.56
Lower Trapezius						
Dominant	125.57(28.55)	127.14(29.23)	123.21(29.23)	.86 (.76, .92)	13.93	22.96
Non-dominant	123.21(39.04)	122.13(32.67)	129.10(30.61)	.85 (.75,.92)	17.75	29.23
Serratus Anterior						
Dominant	245.05(59.55)	249.08(51.40)	248.68(54.35)	.91 (.84,.95)	16.09	37.28
Non-dominant	233.18(48.76)	235.93(49.74)	237.30(48.46)	.92 (.86,.96)	13.44	31.40

Abbreviations: N = Newtons, ICC = intraclass correlation coefficient, SEM = standard error of the measure, MDC₉₀ = 90% boundary limit for the minimal detectable change. N=32

Table 4.3: Between Day Reliability for the Scapular Muscle Endurance Test

Endurance Testing	Time (s)		ICC (95% CI)	SEM (s)	MDC ₉₀ (s)
	Measure 1	Measure 2			
Dominant	89.00(38.81)	103.17(44.00)	.91(.71, .97)	10.31	24.00
Non-dominant	78.17(35.95)	89.42(41.27)	.91 (.73,.97)	10.91	25.38

Abbreviations: s= seconds, ICC = intraclass correlation coefficient, SEM = standard error of the measure, MDC₉₀ = 90% boundary limit for the minimal detectable change. N=12

Table 4.4: Marginal Mean Muscle Thickness Outcomes and Differences Between Limbs

Muscle	Dominant Limb		Non-dominant Limb	
	Relaxed	Contracted	Relaxed	Contracted
Serratus Anterior	.50(.19)	.64(.19)	.52(.16)	.66(.19)
Lower Trapezius	.49(.17)	.63(.19)	.41(.14)	.56(.18)

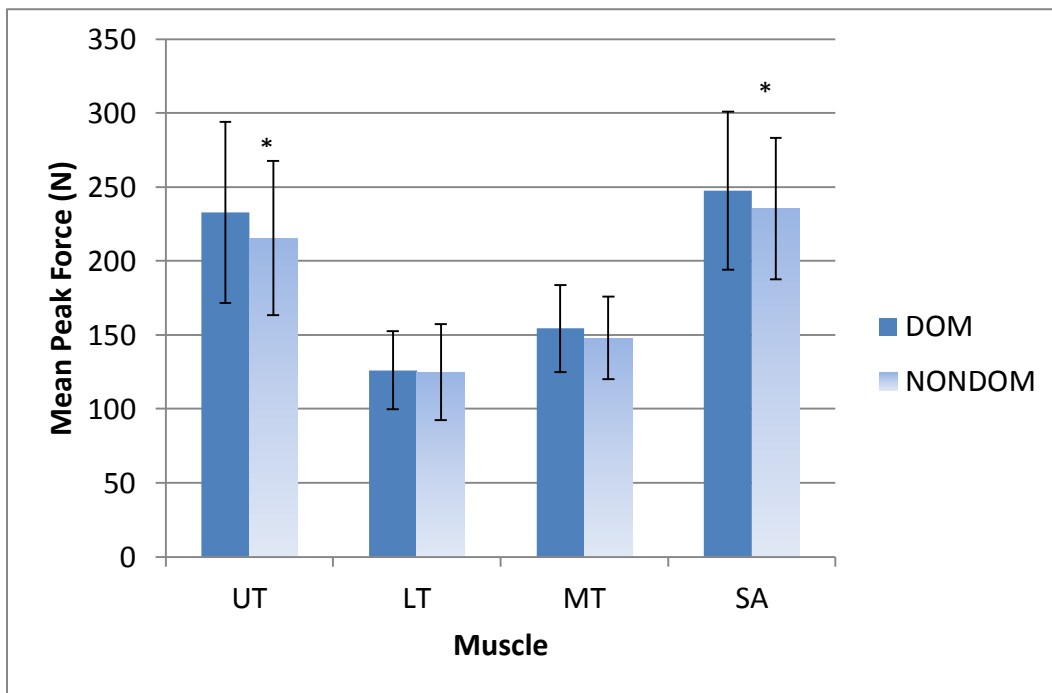
*units are in centimeters (standard deviation), CI = confidence interval, N= 30

Table 4.5: Unadjusted Mean Muscle Thickness Outcomes and Differences Between Limbs

Muscle	Dominant Limb		Non-dominant Limb	
	Relaxed	Contracted	Relaxed	Contracted
Serratus Anterior	.49(.18)	.63(.18)	.51(.15)	.65(.18)
Lower Trapezius	.49(.16)	.63(.18)	.41(.14)	.56(.18)

*units are in centimeters (standard deviation), CI = confidence interval, N= 30

Figure 4.6: Dominant versus Non-dominant Scapular Muscle Strength



Mean force values and standard deviations for scapular muscles are similar when comparing the dominant to non-dominant limbs in middle age healthy individuals. Abbreviations: DOM = Dominant, NONDOM = non-dominant, UT = upper trapezius, LT = lower trapezius, MT = middle trapezius, SA = serratus anterior. * indicates significant different at $p < .05$.

Discussion:

Our first and second hypotheses were partially confirmed as we found a significant increase in dominant limb UT strength, SA strength, and scapular muscle endurance but no significant difference in LT or MT strength. Our third hypothesis was

also partially confirmed as we found no differences for the change in thickness of the SA or LT when comparing the non-dominant limb to the dominant limb in healthy individuals. Although there was a statistically significant increase in UT strength, SA strength, and scapular muscle endurance for the dominant limb compared to the non-dominant limb, the differences were small and do not appear to be clinically meaningful.

Strength with a HHD

Our results add to the limited body of knowledge on the influence of arm dominance on scapular muscle strength. Cools and others investigated the effect of dominance on isometric scapular muscle strength in elite tennis players. Unlike our study, resistance was applied to the distal upper extremity for testing the SA, LT, and MT. However, their results were similar to our findings, as Cools and others also found a significant increase in UT and SA strength for the dominant compared to the non-dominant limb but no differences for the LT and MT.¹⁸³ In contrast to these findings, Another study found higher protraction isokinetic strength on the non-dominant side in elite gymnasts.¹¹⁸ However, caution should be exercised when comparing our results to the aforementioned study because it is difficult to compare isometric to isokinetic results.

The statistically significant increased strength values for the UT and SA dominant limb did not exceed our MDC values. As a result, the differences in UT and SA strength do not appear to be clinically meaningful because the differences in strength between the dominant and non-dominant limbs did not exceed our calculated measurement error. For example, the dominant UT, was nearly 18 N stronger on average than the non-dominant limb and was considered to be statistically significant. However, the MDC values calculated for the UT indicates that an approximate 30 N change was needed to exceed

measurement error of the technique. Overall, arm dominance does not need to be considered when screening scapular muscle strength in healthy individuals of the same population.

Caution should be exercised in making a broad interpretation of our results. It is possible that the influence of dominance on scapular muscle strength could be more pronounced in healthy individuals that routinely perform higher levels of shoulder activity. For example, in a general population of healthy individuals, it has been demonstrated that there are no differences in shoulder rotation strength when comparing the dominant to non-dominant limb.^{47, 170-171, 184} On the contrary, a number of studies looking at specific athletic populations have found increased shoulder and scapular muscle strength for the dominant compared to the non-dominant arms.^{168, 172-173, 183-184} According to these studies, the differences in strength between the dominant and non-dominant limb, for several tested motions, exceeded a 10% difference. In reviewing our data, it appears that a difference of approximately 10% would be needed to meet MDC values for the muscles tested. Overall, populations of individuals that consistently perform high level upper extremity tasks, such as overhead athletes, may develop motor adaptations that result in meaningful increased strength of the dominant limb.

Future studies are needed to investigate dominant and non-dominant scapular muscle strength in a larger population of individuals stratified into groups of shoulder activity levels using the previously described SAL. This will provide a more complete normative database to allow clinicians to make accurate and meaningful interpretations of patient's scapular muscle strength.

Scapular Muscle Endurance

The ability to clinically measure scapular endurance has been reported in the literature yet the reliability and measurement error has yet to be investigated.^{44-45, 121} Because we found the described endurance test to be reliable between days, this test has the potential to be used as a clinical assessment tool. In addition, this was the first study to report a minimal detectable change (MDC) for a sustained scapular isometric endurance test. To that end, a change of 25 seconds was determined to be the MDC needed to reflect a true change of an individual's endurance time. Similar to our findings with UT strength and SA strength, there was a significant increase in scapular muscle endurance for the dominant limb but the differences were well below measurement error. Therefore, it does not appear that dominance plays a meaningful factor in scapular muscle endurance for this population.

Clinical interpretation of our results should be performed cautiously. Upon a closer look at our reliability results for endurance, it appears that a learning effect is occurring between the first and second testing session. For example the mean endurance time increased from day 1 to day 2, approximately 10 seconds, independent of the limb being tested. As suggested from a similar studies testing isometric trunk endurance, multiple trials may be needed before a true baseline measure is obtained.¹⁸⁵ In addition, the endurance MDC may be inflated and would most likely diminish in our study if the ICCs were taken on the second and third trial of testing.

In addition to considering a learning effect, muscular compensation during the endurance test should also be considered when interpreting the results. Although the position used for testing scapular muscle endurance is known to primarily activate the

LT, a strong influence of the UT and other posterior shoulder muscles cannot be ruled out.^{151, 165, 174-175, 186} To that end, a recent EMG study found that the dominant UT was less fatigable than the non-dominant.¹⁸⁷ In the current study, monitoring of the UT was performed by the evaluator, but compensations were difficult to detect. Therefore, it is possible that the endurance results were influenced by the UT.

Future studies are needed to investigate the limitations of the described scapular muscle endurance test. Most importantly, the validity of the test should be investigated by concurrently measuring EMG activity of the posterior shoulder and scapulothoracic muscles. It would also be interesting to quantify compensations through EMG analysis during the endurance test. Future research is also needed to determine the test's sensitivity for detecting differences in endurance times between a pathological and healthy population.

Rehabilitative Ultrasound Imaging

Our RUSI results are in partial agreement with our scapular muscle strength results. There were no differences in LT strength or change in thickness between the dominant and non-dominant arm. In contrast to our hypothesis, no significant differences were found for change in thickness of the SA, but the dominant arm was found to be significantly stronger than the non-dominant arm. The discrepancy found between these measures is likely due to the fact that the arm angle, load, position of the patient, and type of motion were all different between the strength and RUSI tests.

Although not part of our primary aim, there was a significant increase in overall absolute thickness measures for the LT when comparing the dominant and non-dominant limbs. The mean absolute difference, .07cm, was also beyond measurement error found

in Chapter 3. This finding indicates that if absolute thickness measures are used for an outcome measure, dominance should be considered for the LT. As a result, a direct comparison of LT absolute thickness measures cannot be made limb-to-limb.

Alternatively, it is often recommended that change in thickness measures be used in comparisons to reduce the effect of confounding variables, such as limb dominance.¹⁵⁹⁻¹⁶⁰

The observed significant increases in thickness from rest to contraction adds to the current body of knowledge for using RUSI to assess scapular muscle thickness by providing a baseline of normative data. Table 4.5 indicates the mean percent change in thicknesses for this age population is 29% for the dominant LT, 34% for the non-dominant LT, 29% for the dominant SA, and 27% for the non-dominant SA. O'Sullivan and others found similar percent change values for the dominant LT (35%) in a group of healthy, younger and predominately male population.⁵⁶ This information is valuable for future research and clinical use as the procedure for measuring percent change in thickness for the LT and SA in middle age healthy individuals should demonstrate an approximate 30% change from rest to contraction.

There are two important limitations to consider when interpreting the RUSI results. First, no formal validation has been elucidated specifically for the LT and SA. Consequently, change in thickness cannot be interpreted as strength or muscle activity. Second, RUSI has only been shown to detect differences in muscle thickness between rest and contraction for the LT and SA (Chapter 3). Therefore, RUSI may not be sensitive enough to detect small differences in contractility for healthy individuals.

Future RUSI research should validate percent change in thickness concurrently with strength measures or EMG activity. In addition, the sensitivity of the instrument to

detect differences could be investigated by comparing patients with known scapular muscle deficits, as measured with a HHD, to healthy controls.

Limitations

There are two important limitations to this study that should be recognized when interpreting the data. The limb being tested was not blinded by the investigator and thus could result in potential investigator bias of the results. In addition, the validity of most of our outcome measures has not been established. For example, the data reported for SA strength is likely influenced by the co-activation of other shoulder girdle musculature such as the pectoralis major.

Conclusion:

Overall, it does not appear that scapular muscle strength and endurance is clinically different for the dominant and non-dominant limbs in a general middle age healthy population. Therefore, scapular muscle strength should be symmetrical when screening a similar healthy population. Future studies are needed to determine the effect of arm dominance on scapular muscle performance with individuals stratified by shoulder activity levels. Research is also needed to validate the described testing procedures.

Chapter 5 : Scapular Muscle Assessment in Patients with Lateral Epicondylalgia

Introduction:

Lateral epicondylalgia (LE), originally described as lawn tennis elbow,³ is characterized by pain in the region of the lateral epicondyle of the humerus.¹⁸⁸ While a high percentage of recreational tennis players develop the pathology,¹⁰ LE is a common disease with significant consequence in the general population. The prevalence of LE has been reported as high as 12.2% in occupational settings.¹¹ In addition, 27% of patient with LE report severe limitations with activities of daily living,¹³ such as lifting bags or boxes.¹⁴

The efficacy of conservative treatment approaches remains elusive secondary to questions with long term management and high recurrence rates. Cortisone injections are effective in pain management but only up to 8 weeks from the time of the injection.²²⁻²⁵ A recent study reported between a 29% to 38% recurrence rate in individuals receiving conservative treatment management.²⁹ In the only study with a 2 year follow after physiotherapy intervention found that over half the patients reported ongoing pain and functional lost, secondary to a relapse in LE symptoms.³⁰

High recurrence rates and the uncertainty of whether conservative management is having a positive effect on long term outcomes in patients with LE, suggests a component of the rehabilitation process is missing. To that end, a group of studies suggest that assessing scapular muscle impairments is an important component of a proximal upper quarter screen in patients with LE. Lucado and others³⁹ recently reported diminished lower trapezius (LT) muscle strength in a group of female tennis players with LE compared to a matched group of asymptomatic female tennis players.³⁹ In a healthy population of throwing athletes, fatigue of the scapular stabilizers has been shown to

produce kinematic alterations of the elbow.^{188,40} This study implies that scapular muscle fatigue could predispose individuals to injuries in the elbow region by altering elbow kinematics. Another investigator found that induced pain at the upper trapezius (UT) appears to produce an increase in wrist extensor EMG activity in healthy individuals.⁴¹ Clinically, overuse of the UT and underuse of the LT, could result in UT pain. Because pain in the UT has been shown to produce increased activity in the common wrist extensors, increased activity of the common wrist extensors could lead to an overuse injury at the elbow such as LE.

Although it appears scapular muscle strength and endurance has a potential influence on patients with LE, the conclusions that can be drawn from these studies are limited. First, knowledge of scapular muscle strength in patients with LE is limited to a population of female tennis players.³⁹ Because there is a high prevalence of LE in the working population,¹¹ and most studies report that males will develop the condition just as frequently as females,¹⁷ there is a need to investigate scapular muscle strength in a more inclusive group of patients. Second, although the study by Hidetomo and others, implies that fatigued scapular muscles may contribute to elbow pathology,⁴⁰ no studies have directly investigated the influence of scapular muscle endurance on LE patients. Third, scapular muscle strength, as measured in the Lucado and others study, may be influenced by surrounding musculature as the technique cannot completely isolate the influence of one muscle. An assessment tool that can generate quantitative data on a specific scapular muscle behavior, such as rehabilitative ultrasound imaging (RUSI), may be helpful in addressing this limitation.

The primary purpose of this study was to describe scapular strength, endurance, and change in muscle thickness from resting to contraction, as measured by RUSI, in patients with LE compared to matched controls. Our secondary purpose was to examine the same scapular muscle measures in a comparison of the patients involved and uninvolved limbs. The author hypothesizes that there will be a significant decrease in all scapular muscle measures when comparing LE patients to healthy controls. There will be no differences in scapular muscle measures when comparing a patient's involved to uninvolved limb.

Methods

Subjects:

A sample of convenience of 28 (15 female, 13 male) patients with LE agreed to participate in the study. Participants were recruited from 1 of 5 Kentucky Hand and Physical Therapy (KHPT)/ Drayer Physical Therapy outpatient rehabilitation clinics in central Kentucky. As part of standard operational procedures, screening tests for LE and disability scores for each potential participant were recorded during the initial evaluation.

During the initial evaluation, potential pathologic participants presenting with lateral elbow pain underwent a series of inclusion and exclusion criteria testing to determine eligibility for the study. Patients were recruited to participate in this study if they:

- Were seeking medical attention from a therapist at 1 of 5 KHPT/Drayer clinics in central Kentucky
- Reported a primary complaint of unilateral lateral elbow pain
- Were between the ages of 18 and 65
- Presented with and at least two of the following positive clinical tests

1. Pain on palpation of the lateral epicondyle and the associated common wrist extensor unit
2. Passive stretching of extensors (Mill's sign)
3. Pain on gripping a hand dynamometer
4. Pain at the lateral epicondyle during maximal volitional contraction (MVC) of the wrist extensors (Cozen's sign)
5. Pain at the lateral epicondyle while resisting extension of the middle digit (Maudsley's test)^{33, 189}

Patients were excluded from the present study if he or she:

- Reported in their medical history one of the following issues: peripheral neuropathy secondary to diabetes, progressive neurological disorder, cancer, infection in spine or upper extremity, upper motor neurological disorder (eg. stroke, TBI), and fibromyalgia.
- Surgery on the upper quarter within the last 6 months
- Reported a score of less than 10% on the quick version of the disabilities of the arm, shoulder, and hand questionnaire (Quick DASH). A previous study on a healthy population found that normal DASH scores range from 0 to 10.1% in the general population.¹⁹⁰

If the potential participant met the inclusion/exclusion, the evaluating therapist obtained consent. All subjects read and signed an approved consent form by the University of Kentucky's Institutional Review Board. Subject's data from Chapter 4 describing typical values of strength, endurance, and muscle thickness were used for

comparison in our patient populations. The control subjects were specifically matched to an LE patient by age and gender.

Procedures:

A scapular muscle evaluation with the primary investigator was scheduled at that clinic within 2-4 visits after the initial evaluation. The investigator recorded the patient's score on the Quick DASH, which was filled out on the patient's first visit to the clinic as part of standard operational procedures. The patient completed a demographic questionnaire (Appendix C) and patient rated tennis elbow evaluation (PRTEE) (Appendix E). Before the first dependent variable was measured, a baseline resting heart rate was obtained. A 5 minute rest period was given to the patients after each group of dependent variables were measured to allow time for recovery.¹⁷⁹⁻¹⁸⁰ Heart rate was measured immediately after data collection on each dependent variable group and then after the allotted 5 minute rest to ensure the patient had recovered to baseline values. Extra rest was given if the patient did not return to baseline values. (Figure 5.6)

The order for scapular muscle testing was randomized (thickness measures with RUSI, HHD testing, and endurance testing). The order within each scapular test and the first limb tested (dominant versus non-dominant) was also randomized using Microsoft Excel 2007.

1. *Hand Held Dynamometer Manual Muscle Testing*. The procedures described below were followed from 2 previous studies that demonstrated good between day intra-rater reliability for scapular muscle dynamometer strength testing (.75 to .97).^{43, 181} Three MVICs for both the left and right sides was taken. The investigator instructed the patient to push into the dynamometer with their

maximum effort, holding for a 5 second duration. Subjects were instructed to slowly build up their force production to their maximum force by the end of the 5 seconds. The MVC was recorded by the assessor. An attempt was made to isolate the following muscles.

- Serratus Anterior – The patient was positioned supine with the shoulder and elbow flexed to 90°. The dynamometer was placed on the olecranon of the elbow and resistance was given along the humeral axis. The therapist positioned themselves as shown in Figure 5.1.⁴³
- Middle Trapezius – The patient was positioned prone with the elbow extended and shoulder held to 90° abduction. The dynamometer was placed on the spine of the scapula, in between the acromion and the medial superior border of the scapula. The subject was instructed to lift his/her arm upward, while resistance with the dynamometer was being applied in a lateral and anterior direction. The assessor positioned themselves as shown in Figure 5.2.⁴³
- Lower Trapezius - Subject was positioned prone with arm extended and shoulder held to 135° of abduction. The dynamometer was placed in the middle line of the scapula, in between the acromion and the medial superior border of the scapula. While the patient lifted his/her arm upward, resistance with the dynamometer was applied in the lateral and superior direction. The assessor positioned themselves as shown in Figure 5.3.⁴³

2. *Scapular Muscle Endurance testing*

Lying prone, the subjects shoulder was passively positioned to 135° of shoulder abduction. A cuff weight (rounded to .5lbs of 1% of the patient's body weight) was strapped just superior to the elbow. A level was positioned (Figure 5.4) at a height parallel to the trunk and at 135° of shoulder horizontal abduction. The subject was then asked to elevate and hold their arm to the established level for as long possible. The test was terminated when the subject voluntarily lowered their upper extremity or if the subject's distal radius was no longer contacting the level. ⁴⁴⁻⁴⁵

Figure 5.1: Serratus Anterior Strength Testing



Figure 5.2: Middle Trapezius Strength Testing



Figure 5.3: Lower Trapezius Strength Testing



Figure 5.4: Scapular Muscle Endurance Test



3. *Change in Muscle thickness from Rest to Contraction Using RUSI*

Ultrasound imaging data was not collected on all subjects because of patient time constraints or equipment availability. Data was collected on 18 of the 28 available subjects.

Subjects were seated comfortably on a chair without a back. A neutral spine posture was established by instructing the subject to sit upright and then slump three times. After the third movement, the researcher asked the patient to rest comfortably between the 2 motions.¹⁴⁹ The subjects were then asked to place

their forearm on an adjustable table that was elevated to 85° in shoulder elevation and 45° shoulder horizontal abduction. Horizontal abduction was maintained throughout testing by placing a mark for arm position which was monitored continuously by the researcher.

A felt tip mark was placed at the level of the thoracic spine that coincided with the inferior angle of the scapula so that the ultrasound transducer could be placed in a consistent position for all measures.⁴⁹ Additionally a mark was placed on the lateral torso at the level of the inferior angle between the pectoralis major and the latissimus dorsi indicating the location of the serratus anterior (SA).¹⁵⁰

Computerized ultrasonography (General Electric LOGIQ e 2008) was used by the primary investigator to produce a cross sectional image of the LT and SA at rest and during arm lifting. In B mode, a 40mm 8-MHz linear transducer was placed transversely over the mark previously made to identify the LT and vertically along the mark used to identify the SA. A 5lb weight was strapped around each participant proximal to the elbow. A load of 5lbs proximal to the elbow was found to be equivalent in torque to holding a 2lb weight in the hand. In Chapter 3, this load was found to produce a significant change in thickness of the LT and SA from the resting position.

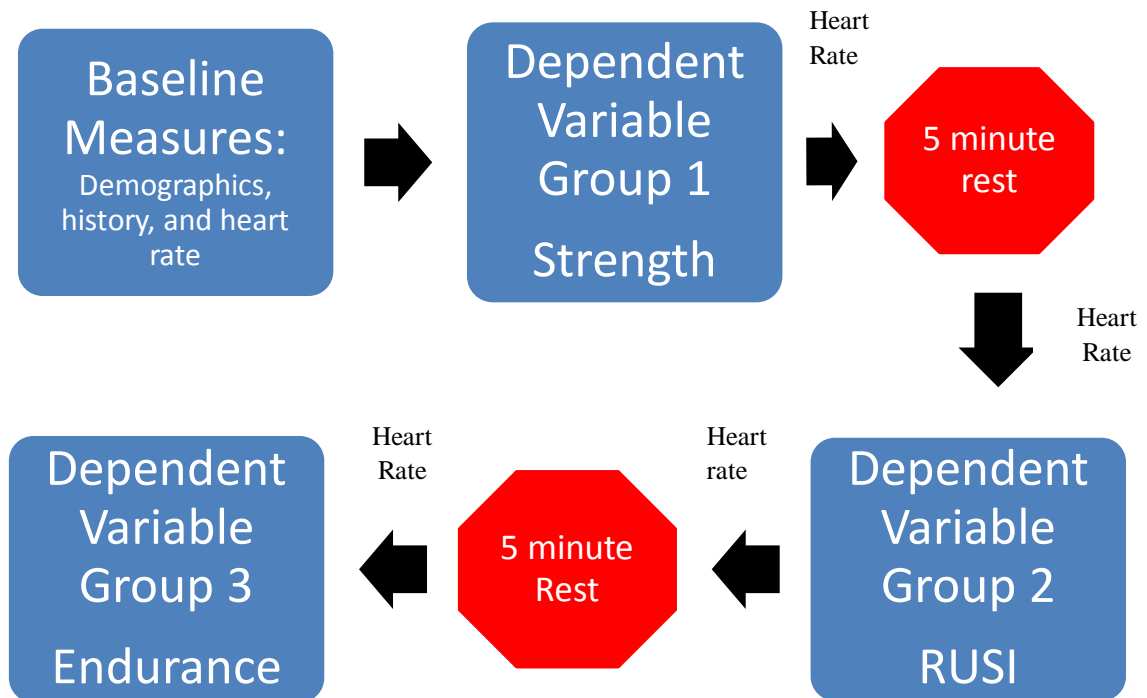
Initially, an image was taken with the muscle in a resting state. Second, the subject was asked to elevate their arm with the elbow extended to 0°, shoulders horizontally abducted to 45° from the frontal plane and shoulder flexion to 90°. This position is known to produce high SA activity and moderate LT activity.

^{151, 165, 175} The arm was then held for approximately 2 seconds to allow an ultrasound images to be taken. A second resting and lifting image was taken for the same arm and muscle using the same procedure. The same procedure was followed in testing the same muscle on the contralateral limb. The entire procedure was then repeated for the other muscle on both limbs.

The primary investigator used an on-screen caliper to obtain the absolute thickness of the LT and SA in resting and during contraction. Linear measurements of the LT thickness were made 2cm from the spinous process landmark.⁴⁹ Linear measurements of the SA were made from the inside border of the rib up to the inside edge of the muscle border. The rib served as the on-screen anatomical reference. The average of 5 thickness measures, spanning the width of the rib, was used for analysis. Muscle thickness was measured twice for the LT as recommended by previous investigators.¹⁵³

Two patients were excluded from the SA RUSI analysis secondary to poor image quality taken during data collection. Therefore, a total of 18 (11 female, 7 males) patients were included for the LT RUSI analysis and 16 (10 female, 6 male) were included for the SA RUSI analysis.

Figure 5.5: Data Collection Procedure Example of One Patient



All procedures were performed in one visit. The order of dependent variable groups were randomized for each patient. Heart rate was measured immediately after data collection on each dependent variable group and then after the allotted 5 minute rest to ensure the patient had recovered to baseline values. Extra rest was given if the participant was not within 10 beats per minute of their baseline heart rate.

Statistical Analyses

An *a priori* power analysis was completed based on previous measures of scapular muscle strength. From this study investigators reported that a MDC of 3.6 kg (30.28 N) can identify true difference between tests for the SA. An effect size of .60 was calculated by dividing the MDC value of 3.6kg and the reported standard deviation of 6.0kg (58.86 N) for the SA. The SA effect size of .60 was chosen for the power analysis because this value was smaller than the effect sizes of the LT and MT.⁴³ Using an effect size of .60, a sample size of 28 patients provided a true power of 86% conducted at $\alpha = .05$.

Statistical Analysis was performed using SPSS version 20 for windows (SPSS Inc. Chicago, IL). Descriptive data for mechanism of injury and duration of symptoms was

calculated for patients with LE. In addition, descriptive data was calculated for the Quick DASH, PRTEE, and all dependent variables for both groups. To evaluate similarity between our control and experimental groups, paired t tests were used to compare age, body mass, height, and shoulder activity levels.

Scapular Muscle Measurement Comparisons Between LE Patients and Controls

The primary purpose was to compare healthy controls to LE patients. For each dependent measure (MT strength, LT strength, SA strength, and endurance) separate 2 way repeated measures ANCOVAs were run using 1 within factor, group (patient or control), and 1 between factor, dominance (whether the dominant or non-dominant limb was involved). Dominance had to be considered as previous healthy subjects were found to have statistical difference due to limb dominance. Because our controls subjects were not matched according to height and weight, these two factors were used as covariates in each model. A p value of .05 was set *a priori*. In the case of an interaction, a least significant difference (LSD) post hoc analysis was performed. If no significant interaction was present, the model was run again without the interaction so that the other factors could be interpreted. The force values used to compare between groups were the average of the 3 trials taken for each muscle tested. A single endurance time in seconds was used for the involved limb.

The other element of the primary purpose was to investigate the differences in muscle thickness (contracting thickness – resting thickness) of the LT and SA between LE patients and controls. Two 3 way repeated measures ANCOVAs were used using 2 within factors (1) condition (rest and contraction) and (2) group (patient and control). Dominance (dominant involved or non-dominant involved) was used as a between factor.

Because our controls subjects were not matched according to height and weight, these two factors were used as covariates in each model. A p value of .05 was set *a priori*. In the case of an interaction, a least significant difference (LSD) post hoc analysis was performed. If no significant interaction was present, the model was run again without the interaction so that the rest of the factors could be interpreted. The average of 2 measures of LT absolute thickness was the dependent measure in one model and the SA absolute thickness was the other dependent measure examined.

LE involved to uninvolved comparison for scapular muscle measures

The secondary purpose was to compare LE patients' uninvolved limb to involved limb. For each dependent measure (MT strength, LT strength, SA strength, and endurance) separate 2 way repeated measures ANOVAs were run using 1 within factor, limb (uninvolved or involved), and 1 between factor, dominance(dominant involved or non-dominant involved). Dominance had to be considered as previous healthy subjects were found to have difference due to limb dominance. A p value of .05 was set *a priori*. In the case of an interaction, a least significant difference (LSD) post hoc analysis was performed. If no significant interaction was present, the model was run again without the interaction so that the other factors could be interpreted. The force values used to compare between limbs were the average of the 3 trials taken for each muscle tested. A single endurance time in seconds was used for the uninvolved and involved limb comparison.

The other element of the secondary purpose was to investigate the differences in muscle thickness of the LT and SA between LE patients and controls. Two 3 way repeated measures ANOVAs were used using 2 within factors (1) condition (rest and

contraction), and (2) limb (uninvolved and involved). Dominance (dominant involved or non-dominant involved) was used as a between factor. A p value of .05 was set *a priori*. In the case of an interaction, a least significant difference (LSD) post hoc analysis was performed. If no significant interaction was present, the model was run again without the interaction so that the other factors could be interpreted. Before analyzing the data, the average of two measures were used to obtain one resting and one contracting thickness value for both the LT and SA.

Results

Age, height, and shoulder activity levels were not statistically different indicating similarity between groups. The LE group was found to have higher Quick DASH scores ($p<.001$) and PRTEE scores ($p<.001$). (Tables 5.1 and 5.2) Among patients with LE, 79% reported an insidious onset, whereas 21% reported a specific event that caused the injury. In LE patients the average duration of symptoms were 19 ± 20 days and 53% reported that the affected side as also the dominant side.

Table 5.1: Patient Characteristics for Strength and Endurance Comparison

Variable	LE Patients (n=28)	Controls (n=28)
Age, y	46.78(8.80)	46.14(9.23)
Body mass, kg	*83.78(15.85)	*73.29(13.25)
Height, m	1.70(.10)	1.71(.09)
Shoulder Activity Level	10.25(4.07)	10.75(4.21)
Quick DASH, %	*40.55(16.30)	*2.59(3.48)
PRTEE, %	*44.20(15.73)	*1.05(1.70)

Abbreviations: y=year, kg=kilograms, m=meters, Quick DASH= quick version of the disability of the arm, shoulder, and hand questionnaire, PRTEE = Patient rated tennis elbow evaluation. Values are mean (SD). The mean for the Shoulder activity Level is based on a scale from 0 (no shoulder activity) to 20 (highest shoulder activity)* Indicates a significant difference in values ($p<.05$)

Table 5.2: Patient Characteristics for Muscle Thickness Comparisons

Variable	LE Patients (n=18)	Controls (n=18)
Age, y	48.17(9.78)	48(10.16)
Body mass, kg	*83.91(17.25)	*69.91(13.00)
Height, m	1.67(.11)	1.71(.08)
Shoulder Activity Level	10.50(3.89)	11.50(4.03)
Quick DASH, %	*38.43(16.76)	*2.01(3.10)
PRTEE, %	*44.78(14.68)	*1.03(1.76)

Abbreviations: y=year, kg=kilograms, m=meters, Quick DASH= quick version of the disability of the arm, shoulder, and hand questionnaire, PRTEE = Patient rated tennis elbow evaluation. Values are mean (SD). The mean for the Shoulder activity Level is based on a scale from 0 (no shoulder activity) to 20 (highest shoulder activity). Two patients from this group of 18 were excluded from the SA analysis because of poor image quality.* Indicates a significant difference in values (p<.05)

Comparison Between LE patients and the Control Group for Strength, Endurance, and

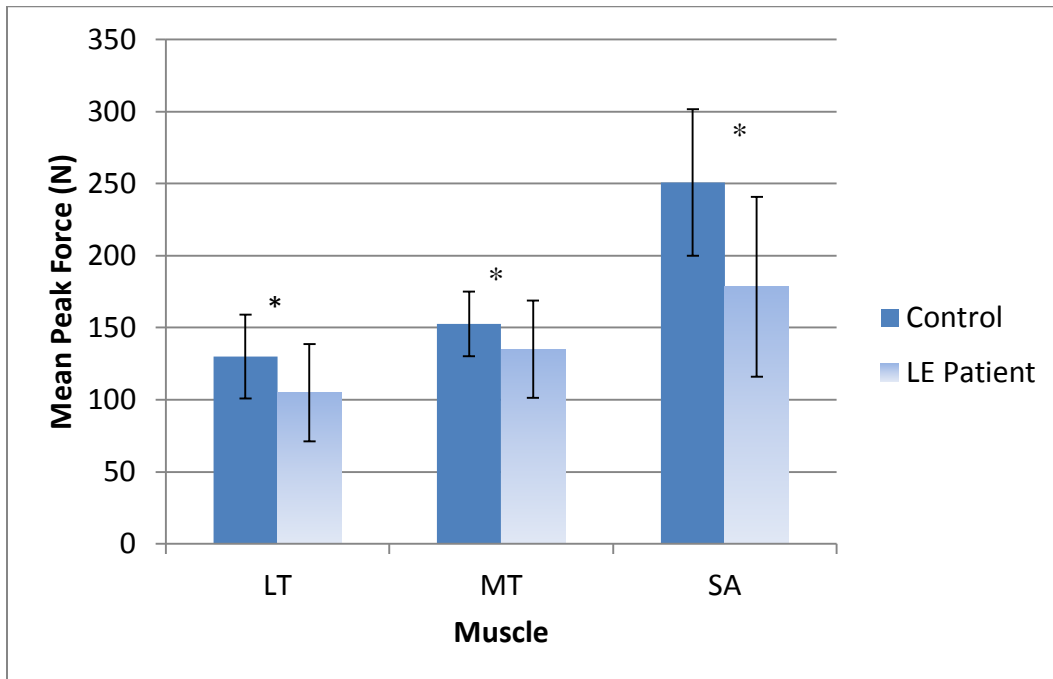
Change in Muscle Thickness

Strength

There was no significant interactions between group and dominance when considering the subjects height and weight (p>.503). There were no differences in limb dominance regardless of group (p>.535). However, the control group was stronger than the LE group when measuring LT strength (p=.006), MT strength (p=.031), and SA strength (p =.000).

(Figure 5.6)

Figure 5.6: Between Groups Marginal Mean Scapular Muscle Strength Values and Standard Deviations

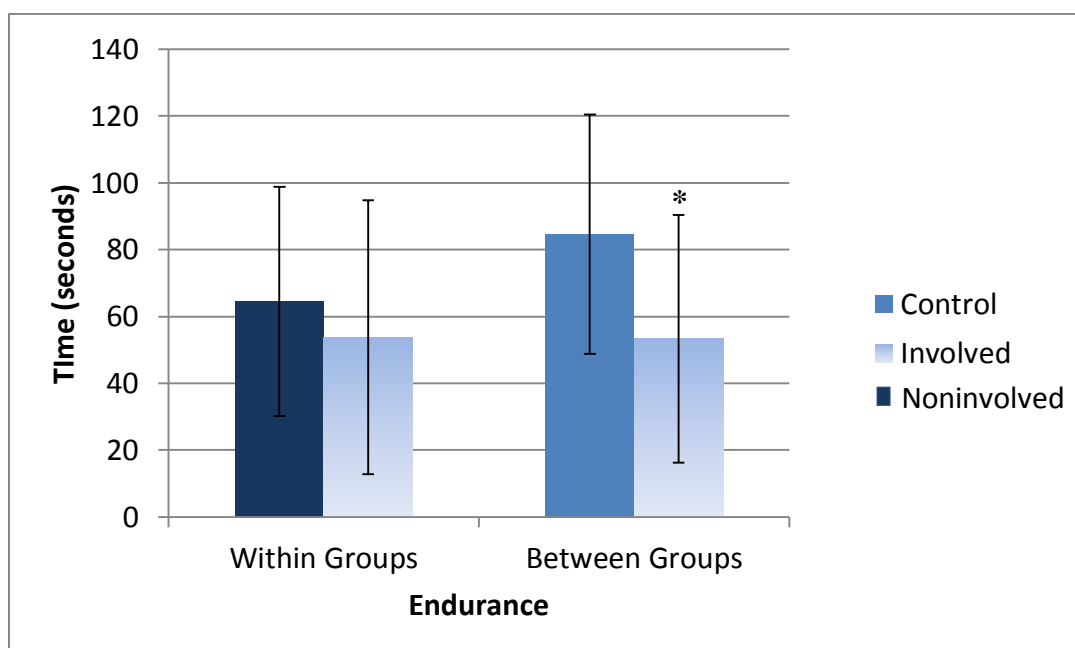


Abbreviations: LT=Lower Trapezius, MT = Middle Trapezius, SA = Serratus Anterior, N=Newtons, LE= lateral epicondylalgia. * Indicates a significant difference between groups ($p < .01$)

Endurance

The same results were found for scapular muscle endurance for interaction ($p = .775$) and dominance ($p = .740$). The control group also had greater endurance than the LE group ($p = .003$). (Figure 5.7)

Figure 5.7: Marginal Mean Scapular Muscle Endurance Values and Standard Deviations



* Indicates a significant difference between groups ($p < .01$). The within groups comparison indicates the comparison between the uninjured and injured limbs in patients with LE. The between groups comparison indicates comparison of healthy controls to patients with LE.

Muscle Thickness

For our SA RUSI outcomes, there was no significant 3 way interaction between muscle type, group, and dominance ($p = .11$). There was a significant 2 way interaction ($p = .028$) between SA thickness condition and group when considering a subjects height and weight. The marginal means indicate that healthy subjects have a greater change in SA thickness (.14cm) relative to patients with LE (.07cm) when considering body weight, height, and arm dominance. (Table 5.3) As expected, the post hoc analysis revealed a significant increases from rest to a contracted condition for the LE patient group ($p < .001$) and control group ($p = .015$). No significant differences were found between the LE patients and control group for resting SA thickness ($p = .919$) or contracting thicknesses ($p = .248$). For the LT muscle thickness analysis, there was no 3 way interaction ($p = .155$)

or 2 way interaction for group and type ($p = .580$). Again, there was a significant increase in thickness from rest to a contracted condition regardless of groups ($p < .001$) (Table 5.3).

Table 5.3: Between Group Comparison of Marginal Mean Values of Scapular Muscle Thickness

Muscle	Marginal Means			
	<i>Control Subjects</i>		<i>LE Patients</i>	
	Relaxed	Contracted	Relaxed	Contracted
Serratus Anterior	.54(.12)	.68(.16)	.54(.16)	.61(.20)
Lower Trapezius	.48(.14)	.61(.17)	.46(.17)	.60(.19)

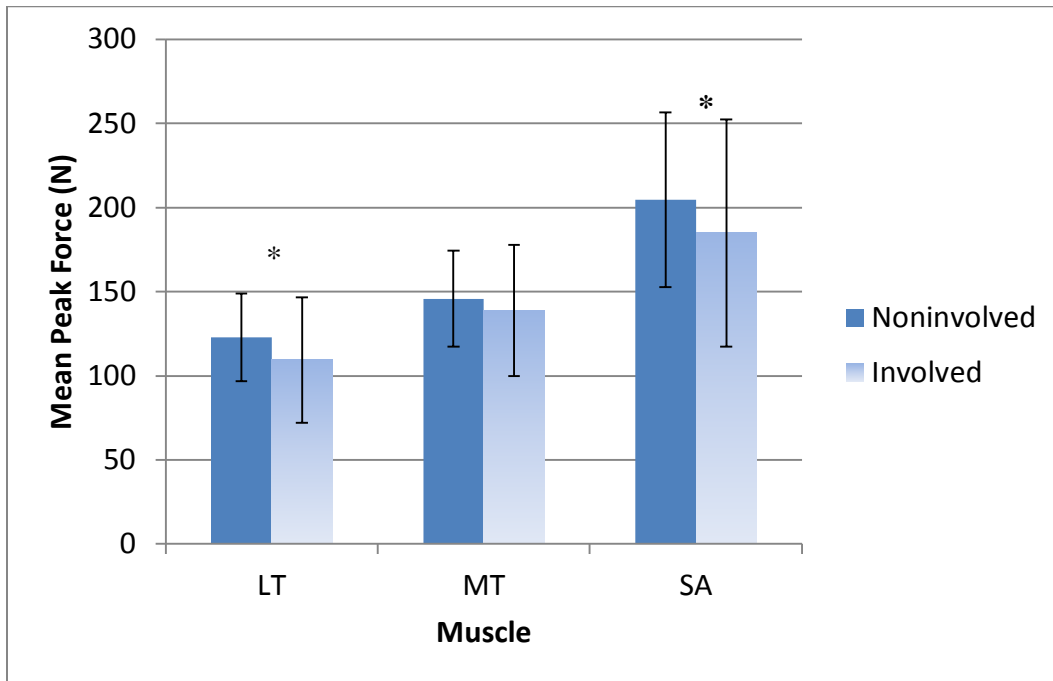
Marginal Means (standard deviation), N=16 for the Serratus anterior, N=18 for the Lower Trapezius

LE involved to uninvolved comparison

Strength

There were no significant interactions between limb and dominance ($p > .381$). There were no differences in dominance regardless of group ($p > .524$). However, the involved limb was weaker than the uninvolved limb when measuring SA strength ($p = .016$) and LT strength ($p = .023$). (Figure 5.8)

Figure 5.8: Within Groups Marginal Mean Scapular Muscle Strength Values and Standard Deviations



Abbreviations: LT=Lower Trapezius, MT = Middle Trapezius, SA = Serratus Anterior, N=Newtons, LE= lateral epicondylalgia.* Indicates a significant difference between groups ($p < .01$)

Endurance

The same results were found for scapular muscle endurance for interaction ($p = .178$) and dominance ($p = .587$). There were no differences in endurance times when comparing the uninvolved and involved limbs ($p = .096$). (Figure 5.7)

Muscle Thickness

For both the SA and LT, there were no significant 3 way interactions between muscle type, limb, and dominance ($p > .071$) or 2 way interactions between type and limb ($p > .444$) for both muscles. Again, there was a significant increase in thickness from rest to a contracted condition regardless of group ($p < .001$) for both muscles (Table 5.4).

Table 5.4: Within LE Group Comparison of Marginal Mean Values of Scapular Muscle Thickness

Muscle	Marginal Means			
	<i>Uninvolved Limb</i>		<i>Involved Limb</i>	
	Relaxed	Contracted	Relaxed	Contracted
Serratus Anterior	.59(.23)	.66(.25)	.59(.25)	.68(.29)
Lower Trapezius	.51(.21)	.65(.23)	.50(.19)	.64(.27)

Marginal Means (SD), N=16 for the Serratus anterior, N=18 for the Lower Trapezius

Discussion:

This was the first study to investigate scapular muscle measures in a general population of patients with LE. In accordance with our primary hypothesis, SA strength, LT strength, MT strength, scapular muscle endurance, and change in SA muscle thickness in patients with LE were significantly less than the healthy matched controls. However, there were no significant differences for the change in LT muscle thickness when comparing LE patients to controls. A direct cause of these scapular impairments cannot be determined from our results, but our findings suggest that scapular muscle strength and endurance should be assessed and potentially treated in patients with LE.

Scapular Muscle Strength and Endurance in Patients with LE

Our results indicated that scapular muscle strength and endurance is impaired in patients with LE compared to matched controls. When comparing a patient's involved limb to uninvolved limb, the differences, although statistically significant for SA and LT strength, do not exceed measurement error using a HHD. These two findings are consistent with previous cross sectional studies on patients with LE. Most closely related to our study, Lucado and others found a significant decrease in LT strength between female tennis players with LE and healthy females tennis players.³⁹ In a second study, Alizadehkhayat and others assessed isometric strength for select shoulder muscles in

patients with LE comparing the results to matched controls and also to the patient's uninjured side. Similar to our study, the authors found that there were deficits in strength when comparing LE patients to matched controls but no meaningful differences in shoulder strength between the uninjured and injured limbs were previously found.³⁶

The current study also demonstrates diminished scapular muscle endurance in patients with LE. This is the first study to evaluate scapular muscle endurance in patients with LE, so there is no previous literature to directly compare our results.

Alizadehkhayat and others.³⁵ examined the same LE population and found no significant differences in rotator cuff muscle endurance compared to a control group.³⁵ The differences between the Alizadehkhayat and others³⁵ findings and our results may be attributed to the type of endurance task as Alizadehkhayat and others investigated repetitive isotonic shoulder contractions compared to the current study in which sustained isometric contraction was used to measure fatigue. In accordance with our findings, patients with chronic low back pain have been found to have deficits in lumbar extensor isometric endurance but the differences for isotonic endurance testing have been inconsistent.¹⁹¹⁻¹⁹² The differences in outcomes between the two types of endurance tests may be due to the physiological differences in muscle contraction types. Intramuscular tissue pressure (MTP) increases during sustained isometric contractions and MTP is known to interfere with muscular blood flow.¹²²⁻¹²³ The impeded blood flow could result in muscle ischemia thus altering muscle performance.¹²⁵⁻¹²⁶ With diminished oxygen delivery, an acceleration of the metabolic process will occur and accelerate muscle fatigue compared to the isotonic test where the muscle acts as a natural pump for blood

flow. Thus, the differences observed in isometric endurance times in the current study, may be a difference in muscle perfusion efficiency between LE patients and controls.

The results of our endurance test are in agreement with our LT strength results. Because the position used to test scapular muscle endurance was the same position used to assess LT strength, one may expect similar results. The position of both tests, prone shoulder abduction at 135°, is known to produce a high amount of LT activity during a brief isometric contraction.^{151, 165, 175} However, it could be argued that because other posterior shoulder muscles are known to be active in this position, this test is not a true measure of LT endurance. Therefore, future research is needed to better determine which of the posterior shoulder muscles are most affected by this test position. Previous studies have compared rate of median frequency shifts between muscles to show which muscle is fatigued at a greater rate.¹⁹³ This approach could be reapplied in order to determine which of the several posterior shoulder muscles are truly fatiguing the fastest indicating which muscle is most affected by this endurance test.

Our findings have implications to clinical practice. The differences in LT strength (25.41 N), SA strength (72.11 N) and endurance values (31.29 seconds) between LE patients and controls all meet or exceed the MDC values reported in Chapter 4. The mean values indicate that the differences are beyond measurement error of the device used. As a result, LT strength, SA strength as well as posterior scapulohumeral endurance should be screened in a LE population of patients early in the rehabilitation processes. The presence of clinically meaningful differences between LE patients and controls, coupled with the finding of no clinically meaningful differences between patients' involved and uninvolved limbs, suggests that scapular muscle deficits may exist even if there are no

differences found between a patient's involved and uninvolved limbs. Because a limb to limb comparison in the clinical setting is often the most convenient way to make assessment, scapular muscle impairments may be missed during an evaluation of patients with LE. Therefore, clinicians should compare strength and endurance deficits in patients with LE to normative data, yet to be established.

The assessment of scapular muscle strength and endurance is potentially important in patients with LE to provide clinicians with objective information to make a clinical decision as to whether treatment of the dysfunction is indicated. Based on this study design, we are unable to definitively determine if treating scapular muscle strength and endurance deficits will improve outcomes in patient with LE. However, it has been demonstrated that after successful remission of pain symptoms, former LE patients continue to present with shoulder weakness.³⁸ According to the kinetic chain theory, during functional arm motions kinetic energy is transferred from proximal to more distal segments of the arm. With an impaired ability to stabilize the scapula, increased energy demands are theoretically required of tissues in the distal upper extremity when performing a functional activity.^{73,75} Therefore, it is possible that scapulohumeral muscle impairments found in this study are not being addressed during a course of treatment and could predispose former LE patients to re-injury. Overall, treating scapulohumeral muscle dysfunction may have a positive impact on long term results and previously reported high recurrence rates, but is yet to be determined.

In treating scapular muscle deficits in patients with LE, our data implies that interventions should focus on both scapular strength and endurance. As a result, tasks focusing just on strength may not be sufficient to address the full range of impairments.

Static endurance of the peri-scapular musculature should be considered in the rehabilitation program. For example, a patient may begin scapular retraction exercises, with feedback for proper activation, while progressing holding times or repetitions. A functional progression of the endurance task could occur later in the rehabilitation process by coupling scapular retraction with repetitive elbow and wrist motions.

Future studies are needed to more completely define the clinical significance of scapular muscle deficits in patients with LE. Specifically, it would be interesting to determine if treating scapular muscle deficits will improve both short and long term outcomes in patients with LE. Longitudinal studies are also warranted to determine if scapular muscle weakness is present prior to the development of LE and if scapular muscle weakness is a potential risk factor for LE.

LT and SA muscle thickness measured by RUSI

This was the first study to assess the behavior of the SA using RUSI on a specific patient population. The results of our study highlight that the change in SA thickness from rest to contraction was significantly different between LE patients and controls. However, using this methodology, LT does not appear to behave differently in patients with LE compared to normal controls. Because of the exploratory nature of using RUSI to measure scapular muscle thickness, readers should interpret these results cautiously.

Our RUSI results for the SA are consistent with our SA strength findings in that both measures demonstrate deficits for the SA in LE patients compared to controls. It is important to note that the differences for the change in SA thickness observed between groups should not be interpreted as decreased strength. Nevertheless, diminished change

in thickness of the SA in LE patients may be further confirmation that the SA muscle is impaired in patients with LE.

Preliminarily, the differences observed between LE patients and controls for the change scores from rest to contraction is encouraging and warrants further investigation. The LE patient group demonstrated a .07 cm larger change in thickness from rest to contraction compared to the control group. From data reported in Chapter 3 and Appendix G, an MDC of .06cm was calculated for the resting position and .08cm when lifting an equivalent load used in this study for the SA. Therefore, change of .07cm is within the calculated range of MDC values. In addition to the absolute differences, the differences in percent change of the SA appear to be substantial between LE patients and controls. Calculated from the unadjusted means in Table 5.5, LE patients exhibited a 12% change in thickness (.59cm to .66cm) and controls exhibited a 29 % change in thickness (.49cm to .63cm). Despite these encouraging results, the observed changes just meet the MDC values and our data is collected on a small sample of the population. As a result, strong clinical recommendations cannot be given. Data collection should be continued on the same population to determine if similar trends continue.

Table 5.5: Between Group Comparison of Unadjusted Mean Values of Scapular Muscle Thickness

Muscle	Unadjusted Means (mm)			
	Control Subjects		LE Patients	
	Relaxed	Contracted	Relaxed	Contracted
Serratus Anterior	.49 (.16)	.63 (.16)	.59(.24)	.66 (.23)
Lower Trapezius	.43(.20)	.56 (.20)	.51(.20)	.65(.21)

Unadjusted Means (SD), N=16 for the Serratus anterior, N=18 for the Lower Trapezius

There is limited literature to which we could compare our results for the SA and LT. Although never validated for the SA or LT, percent change in thickness, as measured

by RUSI, has been shown to be associated with EMG activity of other muscles at lower levels of contraction.¹⁴⁰ In the EMG literature, it has been consistently reported that subjects with cervical pain, shoulder pain, and postural deficits demonstrate diminished SA activity compared to controls, while results for LT activity have been inconsistent.^{96, 194-195} More specific to RUSI, O'Sullivan and others found no significant differences in LT thickness in patients with mild shoulder impingement and healthy controls.⁵⁶ Overall, the findings in our study and in previous studies appear to indicate that subjects with upper quarter pain often present with diminished SA contractility. Independent of pain, healthy subjects with postural deficits also present with diminished SA activity. As a step in the direction of determining the cause of SA deficits in patients with LE, future research should examine proximal upper quarter posture measurements in LE patients compared to controls.

Other future research should place emphasis on validating the SA and LT RUSI procedures. After validation, RUSI could be used to investigate changes in muscle thickness in patients with a pathological condition after an exercise program is administered. In addition, the efficacy of RUSI as a biofeedback tool could be investigated in patients with an impaired SA. Consideration should also be given to a new location for measuring thickness of the LT muscle as it has been argued that measuring thickness 2cm from the spinous process may be too proximal to the tendon insertion of the LT to detect a significant change in thickness if a change is really present.⁵⁶

Limitations

Despite efforts made to eliminate extraneous factors influencing the results of our study, there are several limitations that should be considered. First, although no increased

lateral epicondylar pain was provoked during testing, it could be argued that the results of our study could have been influenced by the patient's fear of movement during the testing. To diminish patient's fear avoidance behaviors, each patient was given a trial on the effected UE for each test before data was recorded. Second, all measures of scapular muscle strength were performed by the primary investigator and the investigator was not blinded to the involved limb in patients with LE, thus introducing potential investigator bias in our results. In addition, the method of evaluating MT and SA strength has not been shown to produce significantly different EMG activity than the surrounding shoulder musculature. Therefore, SA weakness may be conservatively described as shoulder protraction weakness. Finally, a submaximal endurance task is thought to be influenced by an individual's ability to self regulate. Self regulation can cause an individual to override a feeling of fatigue, through the central nervous system, in order to sustain an endurance task.¹⁹⁶ Therefore, it is possible that individuals with LE have a diminished ability to self regulate, thus reducing the endurance times.

There are also limitations specific to the use of RUSI that should be considered. There are no direct studies that provide us with empirical evidence of the validity of a contracted measure of ultrasound imaging for either the LT or SA. Therefore, we are unable to confidently define what the change in muscle thickness from resting to contracting for both the LT and SA represents. In addition, investigator bias was potentially introduced as the primary investigator also measured all muscle thickness images and was not blinded to subject or condition.

Conclusion:

SA and LT measures are significantly diminished in patients with LE when compared to matched controls. Assessment of SA strength, LT strength, and posterior shoulder muscle endurance should be performed in patients with LE. Measures of muscle strength and endurance in patients with LE should be screened early in the rehabilitative process and the results should be compared to normative data as comparisons to the non-involved limbs may produce false negatives. Future studies should seek to validate these outcome measures and investigate the short and long term efficacy of treating scapular muscle deficits as part of a comprehensive treatment program.

Chapter 6 Summary

The first purpose of this dissertation was to explore the reliability and sensitivity of RUSI for measuring thickness of the LT and SA in healthy individuals. The second purpose was to determine the reliability and effect of limb dominance on measures of scapular muscle strength, endurance, and change in muscle thickness of the LT and SA in healthy individuals. The third and primary purpose of this project was to investigate scapular strength, endurance, and change in thickness of the LT and SA in patients with LE.

Hypotheses and Findings for Specific Aim 1

Hypothesis 1: RUSI will demonstrate good to excellent within and between day reliability for measuring absolute muscle thickness of the LT and SA.

Finding: This hypothesis was confirmed as the results show good to excellent ($ICC > .86$) intra-rater reliability for the within and between day measures for both muscles.

Hypothesis 2: A significant increase in load on the shoulders will result in a significant increase in absolute muscle thickness of the LT and SA as measured by RUSI.

Finding: The hypothesis was partially confirmed in that we found a significant increase in absolute muscle thickness for both the serratus anterior (SA) and lower trapezius (LT) when comparing a resting position to a contracted state. However, there were no significant changes in absolute muscle thickness when comparing a low load to a high load for either muscle.

Hypotheses and Findings For Specific Aim 2

Hypothesis 1: Scapular muscle strength, measured with a hand held dynamometer, and a posterior scapular muscle endurance test will be reliably measured within the same day.

Finding: This hypothesis was confirmed as the results show good (ICC >.85) within day intra-rater reliability for all measures of scapular muscle strength. Excellent between day intra-rater reliability (ICC >.91) for the posterior scapular muscle endurance test was also confirmed.

Hypothesis 2: There will be a significant increase in scapular strength, endurance, and change in muscle thickness for the dominant limb compared to the non-dominant limb for all targeted muscles except LT strength and LT change in muscle thickness.

Finding: The hypothesis was partially confirmed in that we found the dominant limb to be statistically stronger than the non-dominant limb for the UT and SA. In addition, a healthy individual's dominant limb had statistically higher endurance times compared to the non-dominant limb. Although the mean UT strength, SA strength, and endurance measures were statistically higher for the dominant arm, the differences did not meet or exceed MDC values. As a result, these significant findings may not be clinically meaningful. There were no significant differences in LT strength, MT strength, change in LT thickness, or change in SA thickness when comparing the dominant to non-dominant limbs in healthy individuals.

Hypotheses and Findings for Specific Aim 3

Hypothesis 1: There will be a statistical and clinically meaningful decrease in scapular muscle strength, endurance, and change in thickness of the LT and SA muscles when comparing patients with LE to healthy controls.

Finding: SA strength, LT strength, MT strength, posterior scapular muscle endurance, and percent change in SA thickness were all statistically diminished when comparing LE patients to matched healthy controls. In addition, the observed differences met or exceeded the minimal detectable change (MDC) values reported in Chapter 4 except for MT strength. There were no differences in the percent change in LT muscle thickness when comparing patients with LE to controls.

Hypothesis 2: There will be no significant differences in scapular muscle strength, endurance, or thickness when comparing an LE patient's involved limb to uninvolved limbs.

Finding: The hypothesis was partially confirmed in that we found no statistical differences in MT strength, endurance, percent change in thickness of the SA, or percent change in thickness of the LT when comparing a patient's involved to uninvolved limb. Although not beyond measurement error, a patient's involved SA and LT were statistically weaker than their uninvolved.

Synthesis and Application of Results

The first study of this dissertation was designed to explore the utility of using Rehabilitative Ultrasound Imaging (RUSI) as a tool to assess scapular muscle thickness in healthy individuals. It was determined that the methods used to assess muscle

thickness of the SA and LT were reliable. The most important finding was that differences between rest and lifting a load could be detected but the differences between a high and low load could not be distinguished. These results would seem to indicate that RUSI when applied using these procedures is only able to distinguish between rest and contraction but not between different levels of contractility in healthy individuals. As to the clinical use of this instrument, RUSI may be able to distinguish between patients with severe LT or SA impairments when compared to a control group.

Although unable to completely isolate the muscle of interest, measures of scapular muscle strength and endurance are more feasible in a clinical setting than RUSI. When performing an evaluation, clinicians frequently compare the involved limb to the uninvolved limb, but it is unknown whether arm dominance plays a factor in measures of scapular muscle strength and endurance. After assessing the effect of arm dominance on scapular muscle strength, endurance and change in thickness of the LT and SA, it was determined that the dominant arm was statistically stronger for the UT and SA and demonstrated higher endurance than the non-dominant arm while no differences could be detected for MT strength, LT strength, or change in muscle thickness measures. It is important to note that the differences in strength and endurance were not large and did not exceed MDC values. Taking into consideration the reliability and responsiveness of the testing procedures with the statistical differences observed indicate that there is no meaningful difference conferred by limb dominance alone with these scapular muscle measurements. Bilateral comparisons of these scapular muscle measurements are encouraged when screening healthy middle aged individuals from a general population.

Interestingly, the literature supports a hypothesis that the influence of arm dominance may be dependent on shoulder activity levels. In general, studies assessing individuals with a high amount of shoulder activity, such as overhead athletes, tend to have larger increases in strength in their dominant arm compared to their non-dominant arm. Before we can definitively conclude that dominance does not have an effect on scapular muscle strength in all populations, future research would be needed to stratify healthy individuals in different groups of shoulder activity levels to assess the effects of arm dominance.

Using the aforementioned scapular outcome measure assessments, the main purpose of this dissertation was to describe scapular muscle behavior in patients with LE. Overall, the results from the third study indicate that SA and LT scapular muscle strength is only slightly diminished when comparing the involved limb to the uninvolved limb in patients with LE. However, when compared to matched controls multiple scapular muscular measurements were found to be deficient beyond measurement error.

There are two important clinical implications from the results of the third study. The small observed differences in our within group comparisons compared to our between group comparison indicates that scapular muscle assessment of patients with LE should be compared to normative values and not just to the patient's uninvolved limb. This finding represents a paradigm shift in the way clinicians make decisions in scapular muscle strength and endurance assessments. In short, if scapular muscle measures are compared to the uninvolved limb in patients with LE, a potentially important clinically finding will likely be missed.

The second important clinical note is that patients with LE present with scapular muscle impairments compared to matched controls. This finding would suggest that an evaluation of scapular muscles is indicated in this patient population. Special consideration should be given to the evaluation of the SA as the differences in both SA strength and change in SA muscle thickness from a resting to a contracted state were large between the LE patients and controls. It should also be emphasized that both strength and endurance were impaired, indicating that a patient's MVIC as well as their ability to sustain a prolonged force production should be assessed.

Furthermore, it is suggested that providing interventions for these impairments may be important in treating patients with LE. According to the kinetic chain theory, during functional arm motions kinetic energy is transferred from proximal to more distal segments of the arm. With an impaired ability to stabilize at the scapula, increased energy demands are theoretically required of tissues in the distal upper extremity when performing a functional activity.^{73,75} Therefore, it is possible that scapulohumeral muscle impairments not addressed during a course of treatment may predispose former LE patients to re-injury. Overall, treating scapulohumeral muscle dysfunction may have a positive impact on long term results and previously reported high recurrence rates.

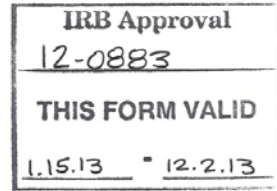
The studies in this dissertation provide insight into how scapular muscle behavior can be evaluated clinically. The studies also describe scapular muscle measures in patients with LE. In chapters 3 and 4, the methodological utility of using RUSI to evaluate muscle thickness, a hand held dynamometer to evaluate strength, and a static posterior scapular muscle endurance test were confirmed by demonstrating good reliability for all measures. The results of Chapter 4 also indicate that limb dominance

does not play a clinically meaningful role in scapular muscle strength, endurance, or change in thickness of healthy middle aged individuals; however more research is needed to make a more definitive conclusion on individuals with higher shoulder activity levels. Using these reliable tools, scapular musculature was found to be deficient in patients with LE compared to controls in Chapter 5.

In conclusion, multiple scapular muscle measurements were found to be deficient, beyond measurement error, in patients with LE compared to controls. However, the differences in scapular muscle measurements when comparing the involved to uninjured limbs were minimal. Assessment of scapular strength and endurance in patients with LE should be obtained and the results compared to normative data, yet to be established. I also recommend treating the above deficits as a means to improve long term results and reduce recurrence rates in patients with LE. Future studies should seek validation for the described endurance test and change in muscle thickness of the SA and LT. In addition, future research should develop normative databases and investigate the efficacy of treating scapular muscle deficits as part of a comprehensive treatment program.

Appendices

Appendix A: Consent Form



Consent to Participate in a Research Study

Scapular Muscle Performance in Patients with Lateral Epicondylalgia and Normal Controls

WHY ARE YOU BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are being invited to take part in this research study because you are a person who is either being treated for lateral elbow pain or you are volunteering to help the researchers investigate scapular muscle behavior in healthy individuals. If you volunteer to take part in this study, you will be one of about 100 people to do so.

WHO IS DOING THE STUDY?

The person in charge of this study is Joseph "Matt" Day from the University of Kentucky Department of Rehabilitation Sciences. He is being guided in this research by Arthur Nitz, PhD, PT and Tim Uhl PhD, ATC, PT. There will be other people on the research team assisting at different times during the study.

WHAT IS THE PURPOSE OF THIS STUDY?

By doing this study, we hope to determine differences in scapular muscle performance between a healthy persons dominant and non-dominant limbs. In addition, we are investigating the differences in scapular muscle performance in patients with lateral elbow pain and healthy people.

ARE THERE REASONS WHY YOU SHOULD NOT TAKE PART IN THIS STUDY?

If you are under 30 or over 65 years of age you do not qualify to take part in this study. You are not eligible for this study if you have had neck, arm, or hand surgery within the last 6 months, currently being treated for cancer, diabetes, stroke, traumatic brain injury, or other criteria as determined by your therapist. If you do not feel comfortable participating in a research study, you should not do so.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

For patients with elbow pain, the study takes place at your Kentucky Hand and Physical Therapy/Drayer (KHPT) clinic. For healthy volunteers, the study will take place at the UK health sciences musculoskeletal lab or one of the KHPT clinics. For patients, testing will be scheduled within your next 2 visits. For healthy volunteers, testing will begin immediately. Completion of an additional questionnaire as well as assessment of the shoulder blade will take approximately 30 minutes. After testing is complete, you will not be asked to give any additional time.

WHAT WILL YOU BE ASKED TO DO?

As part of the study you will be asked to fill out a short questionnaire and you will be asked to participate in the following tests.

Ultrasound testing: A picture of two of your shoulder blade muscles will be taken at rest and while raising your arm using ultrasound imaging. Testing will be performed in a treatment room. Prior to testing, males will be asked to remove their shirts and females will be asked to wear a halter top. You will be asked to sit in a chair while resting pictures are taken. Next you will be asked to lift your arm and hold for 2 seconds while an ultrasound picture is taken.

Shoulder blade muscle strength: To assess shoulder blade strength, the researchers will have you maximally push your arm into a hand gauge that will be held by the therapist. You will be asked to perform 1 test in sitting, 1



on your back, and 2 on your belly. For patients, these tests are designed to detect shoulder blade strength without causing additional pain in the elbow.

Shoulder blade muscle endurance: This test will be used to evaluate the endurance of your shoulder blade muscles. For the first test, you will be asked to prop on your elbows while laying on your belly. You will then be instructed to hold that position until fatigue. For the second endurance tests, you will be asked to lay on your stomach and hold your arm up until fatigue. You will also have a weight cuff placed above your elbow. The weight will be 1% of your body weight.

Elbow Muscle testing: For healthy volunteers, a series of 5 short tests will be performed on both elbows to ensure that you don't have signs of elbow tendonitis.

If you are a patient, we will also review your medical/physical therapy records.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

Minimal risk is associated with this study. An increase in shoulder pain or muscle soreness may arise from the exam that may last between 24-48 hours. This typically resolves without any treatment needed. We will do everything we can to keep you from being harmed. In addition to the risks listed above, you may experience a previously unknown risk or side effect.

WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?

For patients, information from this study may, in the future, help clinicians determine the best treatment approach for patients with similar conditions. In addition, information obtained from this study will be given to your treating therapist. Healthy volunteers will receive an optional scapular muscle exercise progression in the form of a handout.

DO YOU HAVE TO TAKE PART IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering. For patients, if you decide not to take part in this study, you will receive the same care that a patient would typically receive at a KHPT clinic.

IF YOU DON'T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

Because this study does not provide a treatment, there are no other options available to the patient. However, your treatment will not be effected by your choice to volunteer

WHAT WILL IT COST YOU TO PARTICIPATE?

There is no additional costs to patients or healthy volunteers participating in the study. For the purposes of this study, your insurance company will not be billed for the time you spend volunteering.

WHO WILL SEE THE INFORMATION THAT YOU GIVE?

We will make every effort to keep private all research records that identify you to the extent allowed by law. Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private. The data collected in this study will be included in a larger database in the musculoskeletal laboratory at the University of Kentucky. The information we obtain from you may be combined and used in future research studies relating to other injuries however, with all personal information removed.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. Information collected for the study will be kept at KHPT following the standard protocol for record keeping and research data collected will be kept in a locked cabinet in Room 222 of the CT Wethington Building at the University of Kentucky after the study is complete. You should know, however, that there are some circumstances in which we may have to show your information to other people. Agents of Kentucky Hand and Physical Therapy and the University of Kentucky will be allowed to inspect or copy pertinent sections of your medical and research records related to this study that identify you.

CAN YOUR TAKING PART IN THE STUDY END EARLY?

If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. You will not be treated differently if you decide to stop taking part in the study.

The individuals conducting the study and/or your treating therapist may need to withdraw you from the study.

This may occur if you are not able to follow the directions they give you, if they find that your being in the study is



more risk than benefit to you, or if your physician determines your pain to be caused by an injury that does not qualify you for this study.

ARE YOU PARTICIPATING OR CAN YOU PARTICIPATE IN ANOTHER RESEARCH STUDY AT THE SAME TIME AS PARTICIPATING IN THIS ONE?

You may take part in this study if you are currently involved in another research study. It is important to let the investigator and your therapist know if you are in another research study. You should also discuss with the investigator before you agree to participate in another research study while you are enrolled in this study.

WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?

If you believe you are hurt or if you get sick because of something that is done during the study, you should call your therapist immediately. He or she will determine what type of treatment, if any, that is best for you at that time.

It is important for you to understand that the University of Kentucky and Kentucky Hand and Physical Therapy will not pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. That cost will be your responsibility. Also, the University of Kentucky and Kentucky Hand and Physical Therapy will not pay for any wages you may lose if you are harmed by this study.

Usually, medical costs that result from research-related harm cannot be included as regular medical costs. The University of Kentucky and Kentucky Hand and Physical Therapy are not allowed to bill your insurance company, Medicare, or Medicaid for these costs without first getting permission. You should ask your insurer if you have any questions about your insurer's willingness to pay under these circumstances. Therefore, the medical costs related to your care and treatment because of research related harm will be your responsibility. You do not give up your legal rights by signing this form.

WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

You will not receive any rewards or payment for taking part in the study. Your willingness to take part, however, may, in the future, help therapist better understand and/or treat others who have your condition.

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the primary investigator, Matt Day, at (937) 231 - 8231. If you have any questions about your rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky at 859-257-9428 or toll free at 1-866-400-9428. We will give you a signed copy of this consent form to take with you.

WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT YOUR DECISION TO PARTICIPATE?

If the researcher learns of new information in regards to this study, and it might change your willingness to stay in this study, the information will be provided to you. You may be asked to sign a new informed consent form if the information is provided to you after you have joined the study.

Signature of person agreeing to take part in the study

Date

Printed name of person agreeing to take part in the study

Name of [authorized] person obtaining informed consent

Date

Signature of Investigator

Appendix B: Medical History and Demographics for Normal Controls

1. Name _____ Gender _____ Age _____
2. Weight _____ Height _____ Dominant arm/hand _____ Occupation _____
3. What is your estimated physical demand level at work (see below)?

Physical Demand Level	Occasional 0 -33% of the work day	Frequent 34 -66% of the work day	Constant 67 -100% of the work day
Sedentary	10 lbs	Negligible	Negligible
Light	20lbs	10lbs	Negligible
Medium	20-50lbs	10-25lbs	10lbs
Heavy	50-100lbs	25-50lbs	10-20lbs
Very Heavy	>100lbs	>50lbs	>20lbs

4. Please indicate with an “x” how often you performed each activity in your healthiest and most active state, in the past year.

	Never or less than once a month	Once a month	Once a week	More than once a week	Daily
Carrying objects 8lbs or heavier by hand (such as a bag of groceries)					
Handling Objects Overhead					
Weight lifting or weight training with Arms					
Swing motion (hitting a ball)					
Lifting objects 25lbs or heavier (not weight lifting)					

- Do you participate in contact sports (such as but not limited to American football, rugby, soccer, basketball, wrestling, boxing, lacrosse, martial arts, ect)?
 - a. No
 - b. Yes, without organized officiating
 - c. Yes, with organized officiating
 - d. Yes, at a professional level (i.e. paid to play)
 - Do you participate in contact sports that involve hard overhand throwing (such as baseball, cricket, or quarterback), overhead serving (such as tennis or volleyball), or lap/distance swimming?
 - a. No
 - b. Yes, without organized officiating
 - c. Yes, with organized officiating
 - d. Yes, at a professional level (i.e. paid to play)
5. Were you an athlete? Y or N If so, what sport(s)?
6. Please list injuries or surgeries you have had in the last 6 months?

Appendix C: Medical History and Demographics for Patients

1. **Name** _____ **Gender** _____ **Age** _____
2. **Weight** _____ **Height** _____ **Dominant arm/hand** _____ **Occupation** _____
3. **What is your estimated physical demand level at work (see below)?**

Physical Demand Level	Occasional 0 -33% of the work day	Frequent 34 -66% of the work day	Constant 67 -100% of the work day
Sedentary	10 lbs	Negligible	Negligible
Light	20lbs	10lbs	Negligible
Medium	20-50lbs	10-25lbs	10lbs
Heavy	50-100lbs	25-50lbs	10-20lbs
Very Heavy	>100lbs	>50lbs	>20lbs

4. **Please indicate with an “x” how often you performed each activity in your healthiest and most active state, in the past year.**

	Never or less than once a month	Once a month	Once a week	More than once a week	Daily
Carrying objects 8lbs or heavier by hand (such as a bag of groceries)					
Handling Objects Overhead					
Weight lifting or weight training with Arms					
Swing motion (hitting a ball)					
Lifting objects 25lbs or heavier (not weight lifting)					

- Do you participate in contact sports (such as but not limited to American football, rugby, soccer, basketball, wrestling, boxing, lacrosse, martial arts, ect)?
 - e. No
 - f. Yes, without organized officiating
 - g. Yes, with organized officiating
 - h. Yes, at a professional level (i.e. paid to play)
 - Do you participate in contact sports that involve hard overhand throwing (such as baseball, cricket, or quarterback), overhead serving (such as tennis or volleyball), or lap/distance swimming?
 - e. No
 - f. Yes, without organized officiating
 - g. Yes, with organized officiating
 - h. Yes, at a professional level (i.e. paid to play)
5. **Were you an athlete? Y or N If so, what sport(s)?**

6. **How did you get hurt?**

7. Have you had to miss work because of the injury? Y or N If so, how many days?

8. How long have you been injured?

9. Which elbow is affected?

Appendix D: Survey of Upper Extremity Disability Quick (DASH)

The Disability of the arm, shoulder and hand (DASH) is a questionnaire to ask you about your symptoms as well as your ability to perform certain activities. Please answer every question, based on your condition in the last week, by circling the appropriate number. If you did not have the opportunity to perform an activity in the past week, please make your best estimate on which response would be most accurate. It does not matter which hand you use to perform the activity; please answer based on your ability regardless of how you perform the task. Please rate your ability to do the following activities by circling the number:

	No Difficulty	Mild Difficulty	Moderate Difficulty	Severe Difficulty	Unable
Open a tight jar	1	2	3	4	5
Do heavy household chores (e.g., wash walls, floors)	1	2	3	4	5
Carry a shopping bag or briefcase	1	2	3	4	5
Wash your back	1	2	3	4	5
Use a knife to cut food	1	2	3	4	5
Recreational activities which you take some force or impact through your arm, shoulder, or hand (golf, hammering, tennis, etc)	1	2	3	4	5
	Not at All	Slightly	Moderately	Quite a Bit	Extremely
During the past week, to what extent has your arm, shoulder, or hand problem interfered with your normal social activities with family, friends, neighbors, or groups?	1	2	3	4	5
	Not Limited at All	Slightly Limited	Moderately Limited	Very Limited	Unable
During the past week, were you limited in your work or other regular daily activities, as a result of your arm, shoulder, or hand problem?	1	2	3	4	5
Please rate the severity of the following symptoms in the last week	None	Mild	Moderate	Severe	Extreme
Arm, shoulder, or hand pain	1	2	3	4	5
Tingling (pins & needles) in your arm, shoulder, or hand.	1	2	3	4	5
	No Difficulty	Mild Difficulty	Moderate Difficulty	Severe Difficulty	So Much I can't Sleep
During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand?	1	2	3	4	5
<i>For office use only</i> Percent Disability Score () Sum all columns for raw score ()					

Appendix E: Patient Rated Tennis Elbow Evaluation

PATIENT-RATED TENNIS ELBOW EVALUATION

Name _____ Date _____

The questions below will help us understand the amount of difficulty you have had with your arm in the past week. You will be describing your average arm symptoms over the past week on a scale 0-10. Please provide an answer for all questions. If you did not perform an activity because of pain or because you were unable, then you should circle a "10". If you are unsure please estimate to the best of your ability. Only leave items blank if you never perform that activity. Please indicate this by drawing a line completely through the question.

1. PAIN in your affected arm											
<i>Rate the average amount of pain in your arm over the past week by circling the number that best describes your pain on a scale from 0-10. A zero (0) means that you did not have any pain and a ten (10) means that you had the worst pain imaginable.</i>											
RATE YOUR PAIN:											
	No Pain									Worst Imaginable	
When your are at rest	0	1	2	3	4	5	6	7	8	9	10
When doing a task with repeated arm movement	0	1	2	3	4	5	6	7	8	9	10
When carrying a plastic bag of groceries	0	1	2	3	4	5	6	7	8	9	10
When your pain was at its least	0	1	2	3	4	5	6	7	8	9	10
When your pain was at its worst	0	1	2	3	4	5	6	7	8	9	10

Please turn the page.....

2. FUNCTIONAL DISABILITY

A. SPECIFIC ACTIVITIES

Rate the **amount of difficulty** you experienced performing each of the tasks listed below, over the past week, by circling the number that best describes your difficulty on a scale of 0-10. A **zero (0)** means you **did not experience any difficulty** and a **ten (10)** means it was so difficult you were unable to do it at all.

	No Difficulty	0	1	2	3	4	5	6	7	8	9	10	Unable To Do
Turn a doorknob or key		0	1	2	3	4	5	6	7	8	9	10	
Carry a grocery bag or briefcase by the handle		0	1	2	3	4	5	6	7	8	9	10	
Lift a full coffee cup or glass of milk to your mouth		0	1	2	3	4	5	6	7	8	9	10	
Open a jar		0	1	2	3	4	5	6	7	8	9	10	
Pull up pants		0	1	2	3	4	5	6	7	8	9	10	
Wring out a washcloth or wet towel		0	1	2	3	4	5	6	7	8	9	10	

B. USUAL ACTIVITIES

Rate the **amount of difficulty** you experienced performing your **usual** activities in each of the areas listed below, over the past week, by circling the number that best describes your difficulty on a scale of 0-10. By "usual activities", we mean the activities that you performed **before** you started having a problem with your arm. A **zero (0)** means you did not experience any difficulty and a **ten (10)** means it was so difficult you were unable to do any of your usual activities.

1. Personal activities (dressing, washing)		0	1	2	3	4	5	6	7	8	9	10
2. Household work (cleaning, maintenance)		0	1	2	3	4	5	6	7	8	9	10
3. Work (your job or everyday work)		0	1	2	3	4	5	6	7	8	9	10
4. Recreational or sporting activities		0	1	2	3	4	5	6	7	8	9	10

Comments:

Appendix F: Explanation for Endurance Testing

1. The therapist will place your arm at a specified location. A level will be placed above your arm to specify the height of the arm position. (See picture)
2. We will ask you to hold your arm at this position for as long as possible while squeezing your shoulder blade down and back. (See picture)
3. It is important that you give us maximum effort during the testing.

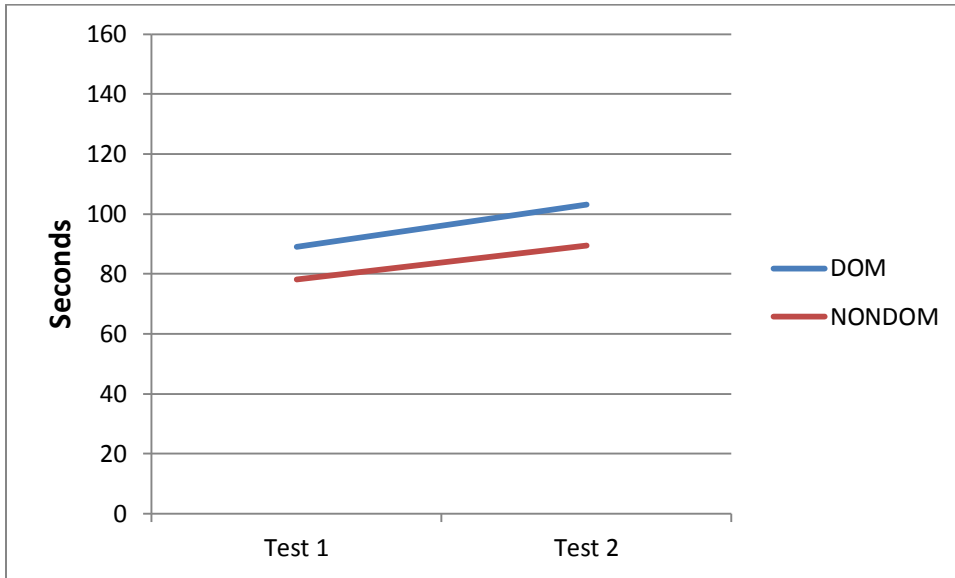


Appendix G: Psychometric Properties for a 2lb Lifting Condition Performed with
Ultrasound Imaging not Reported in Chapter 3

Muscle	Mean Thickness (cm)		ICC (95% CI)	SEM (cm)	MDC⁹⁵ (cm)
	Measure 1	Measure 2			
Lower Trapezius	.53(.20)	.54(.20)	.98(.95, 1.0)	.03	.08
Serratus Anterior	.75(.20)	.75(.21)	.98 (.95, .99)	.03	.08

MDC⁹⁵ = 95% boundary limit for minimal detectable change. ICC = intraclass correlation coefficient and 95% confidence interval for within day measures. SEM = standard error of the measure

Appendix H: Between Day Trends for the Scapular Muscle Endurance Test in Healthy Individuals



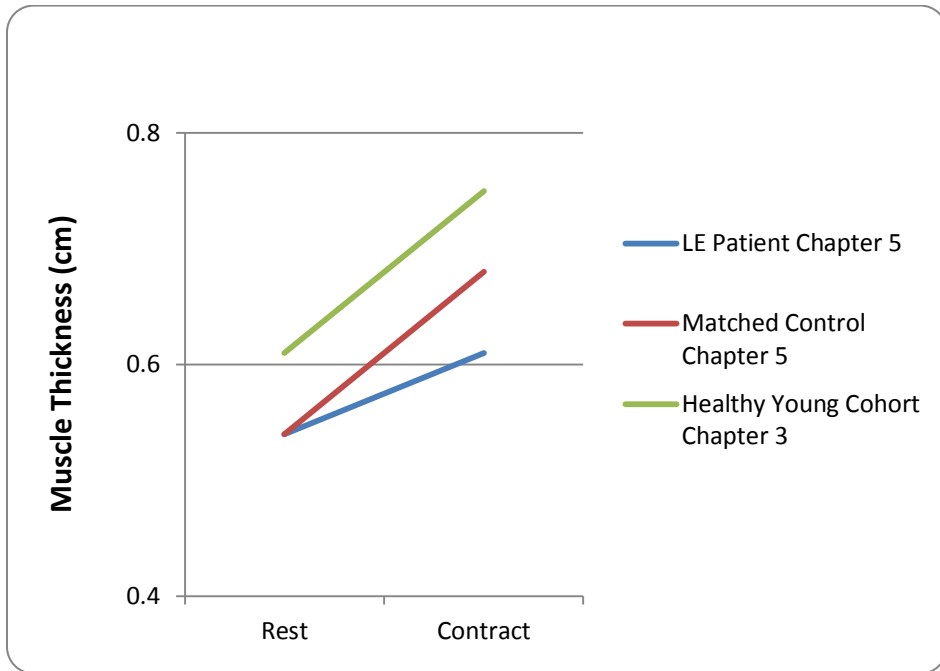
DOM = dominant limb, NONDOM = non-dominant limb. Test 1 and 2 were performed approximately 1 week apart. The trend observed for increased endurance time from day 1 to day 2 indicates that a learning effect may have occurred between days.

Appendix I: Comparison of Mean Scapular Muscle Strength Values Recorded in Chapter 4 to Previously Reported Data

Muscle	Current Study		Celik et al ¹⁸¹
	Dominant	Non-dominant	
Upper Trapezius	232.69 (61.14)	215.45 (52.19)	191.8 (40.3)
Lower Trapezius	125.97 (26.39)	124.81 (32.50)	129.7 (32.7)
Middle Trapezius	154.28(29.42)	148.03 (27.97)	138.3 (34.2)
Serratus Anterior	247.60 (53.48)	235.46 (47.73)	156.2 (42.6)

Values are reported in Newtons. (Standard Deviation). The values reported by Celik et al did not distinguish between dominance. The values reported in the current study are the average of three trials, whereas the values reported by Celik et al are the result of 1 trial. The differences in UT and SA strength values between studies is likely due to the differences in BMI of the primary investigator (Celik et al BMI = 18.75kg/m², Current study BMI = 23.60kg/m²)

Appendix J: Comparison of Absolute Serratus Anterior Thickness Values Across Studies



Load lifted during contraction was equivalent to lifting 2lbs of weight held in the hand. The change in thickness from rest to contraction (.14cm) was consistent for the matched control group and the young healthy cohort. Change in thickness for the LE group was only half the difference from rest to contraction (.07cm) when compared to the other 2 healthy groups.

Appendix K: Mean Heart Rates and Standard Deviations for LE patients and Controls
During Data Collection

Dependent Variable	Heart Rate			
	<i>Control Subjects</i>		<i>LE Patients</i>	
	Pre	Post	Pre	Post
Strength	66.25(6.83)	70.71(8.35)	66.73(6.32)	72.57(8.09)
Endurance	66.71(6.56)	75.75(7.84)	67.10(8.37)	74.67(10.61)
Ultrasound	65.0(6.84)	66.72(6.83)	65.5(8.02)	67.0(7.62)

Heart rate is measured in beats per minute. The order of testing was randomized and at least 5 minutes of rest was given between each dependent variable. N = 28 for strength and endurance measures. N = 18 for ultrasound measures.

Appendix L: Comparison of Mean Scapular Muscle Strength Values Recorded for LE Patients in Chapter 5 to Previously Reported Data on Patients with Shoulder Pathology

Muscle	LE Patients (Chapter 5)	Shoulder Patients (Michener et al⁴³)
Lower Trapezius	10.68(3.44)	10.5(4.0)
Middle Trapezius	13.77(3.44)	11.9(3.1)
Serratus Anterior	18.19(6.35)	15.2(6.0)

Mean strength values and (standard deviations) are reported in kilograms. LE patients N = 28/ Percent male = 46.4%, Shoulder patients N = 40/Percent male = 37.5%. Mean Age, height, and weight were similar between groups.

References

1. Magee D. *Orthopaedic Physical Assessment*. 4th ed. St. Louis: Saunders; 2006.
2. Waugh EJ. Lateral epicondylalgia or epicondylitis: what's in a name? *J Orthop Sports Phys Ther*. Apr 2005;35(4):200-202.
3. Morris H. The rider's sprain. *Lancet*. 1882;120:133-134.
4. Alfredson H, Ljung BO, Thorsen K, Lorentzon R. In vivo investigation of ECRB tendons with microdialysis technique--no signs of inflammation but high amounts of glutamate in tennis elbow. *Acta Orthop Scand*. Oct 2000;71(5):475-479.
5. Chard MD, Cawston TE, Riley GP, Gresham GA, Hazleman BL. Rotator cuff degeneration and lateral epicondylitis: a comparative histological study. *Ann Rheum Dis*. Jan 1994;53(1):30-34.
6. Potter HG, Hannafin JA, Morwessel RM, DiCarlo EF, O'Brien SJ, Altchek DW. Lateral epicondylitis: correlation of MR imaging, surgical, and histopathologic findings. *Radiology*. Jul 1995;196(1):43-46.
7. Vicenzino B, Paungmali A, Buratowski S, Wright A. Specific manipulative therapy treatment for chronic lateral epicondylalgia produces uniquely characteristic hypoalgesia. *Man Ther*. Nov 2001;6(4):205-212.
8. Hong QN, Durand MJ, Loisel P. Treatment of lateral epicondylitis: where is the evidence? *Joint Bone Spine*. Sep 2004;71(5):369-373.
9. Yaxley G, Jull GA. Adverse Tension in the Neural System: A preliminary study of tennis elbow. *Aust J Physiother*. 1993;39:16-22.
10. Gruchow HW, Pelletier D. An epidemiologic study of tennis elbow. Incidence, recurrence, and effectiveness of prevention strategies. *Am J Sports Med*. Jul-Aug 1979;7(4):234-238.
11. Shiri R, Viikari-Juntura E. Lateral and medial epicondylitis: role of occupational factors. *Best Pract Res Clin Rheumatol*. Feb 2011;25(1):43-57.
12. Herquelot E, Bodin J, Roquelaure Y, et al. Work-related risk factors for lateral epicondylitis and other cause of elbow pain in the working population. *Am J Ind Med*. Nov 13 2012.
13. Walker-Bone K, Palmer KT, Reading I, Coggon D, Cooper C. Occupation and epicondylitis: a population-based study. *Rheumatology (Oxford)*. Feb 2012;51(2):305-310.
14. Walker-Bone K, Palmer KT, Reading I, Coggon D, Cooper C. Prevalence and impact of musculoskeletal disorders of the upper limb in the general population. *Arthritis Rheum*. Aug 15 2004;51(4):642-651.
15. Korthals-de Bos IB, Smidt N, van Tulder MW, et al. Cost effectiveness of interventions for lateral epicondylitis: results from a randomised controlled trial in primary care. *Pharmacoeconomics*. 2004;22(3):185-195.
16. Silverstein B, Adams D, Kalat J. Work Related Musculoskeletal Disorders in the NEck, Back, and Upper Extremity in Washington State, 1994 -2002. *SHARP Technical Report Number 40-8a-2004*. 2005.
17. Hamilton PG. The prevalence of humeral epicondylitis: a survey in general practice. *J R Coll Gen Pract*. Oct 1986;36(291):464-465.
18. Allander E. Prevalence, incidence, and remission rates of some common rheumatic diseases or syndromes. *Scand J Rheumatol*. 1974;3(3):145-153.

19. Haahr JP, Andersen JH. Prognostic factors in lateral epicondylitis: a randomized trial with one-year follow-up in 266 new cases treated with minimal occupational intervention or the usual approach in general practice. *Rheumatology (Oxford)*. Oct 2003;42(10):1216-1225.
20. Lewis M, Hay EM, Paterson SM, Croft P. Effects of manual work on recovery from lateral epicondylitis. *Scand J Work Environ Health*. Apr 2002;28(2):109-116.
21. Lo MY, Safran MR. Surgical treatment of lateral epicondylitis: a systematic review. *Clin Orthop Relat Res*. Oct 2007;463:98-106.
22. Coombes BK, Bisset L, Vicenzino B. Efficacy and safety of corticosteroid injections and other injections for management of tendinopathy: a systematic review of randomised controlled trials. *Lancet*. Nov 20 2010;376(9754):1751-1767.
23. Olausson M, Holmedal O, Lindbaek M, Brage S. Physiotherapy alone or in combination with corticosteroid injection for acute lateral epicondylitis in general practice: a protocol for a randomised, placebo-controlled study. *BMC Musculoskelet Disord*. 2009;10:152.
24. Orchard J. Corticosteroid injection for lateral epicondylalgia is helpful in the short term, but harmful in the longer term; data for non-corticosteroid injections and other tendinopathies are limited. *Evid Based Med*. Aug 2011;16(4):116-117.
25. Han SH, An HJ, Song JY, et al. Effects of corticosteroid on the expressions of neuropeptide and cytokine mRNA and on tenocyte viability in lateral epicondylitis. *J Inflamm (Lond)*. Oct 30 2012;9(1):40.
26. Centre for Evidence-Based Medicine, Oxford University. Levels of evidence and grades of recommendation. http://www.cebm.net/levels_of_evidence.asp.
27. Bisset L, Paungmali A, Vicenzino B, Beller E. A systematic review and meta-analysis of clinical trials on physical interventions for lateral epicondylalgia. *Br J Sports Med*. Jul 2005;39(7):411-422; discussion 411-422.
28. Dingemans R, Randsdorp M, Koes BW, Huisstede BM. Evidence for the effectiveness of electrophysical modalities for treatment of medial and lateral epicondylitis: a systematic review. *Br J Sports Med*. Jan 18 2013.
29. Coombes BK, Bisset L, Brooks P, Khan A, Vicenzino B. Effect of corticosteroid injection, physiotherapy, or both on clinical outcomes in patients with unilateral lateral epicondylalgia: a randomized controlled trial. *JAMA*. Feb 6 2013;309(5):461-469.
30. Nilsson P, Baigi A, Sward L, Moller M, Mansson J. Lateral epicondylalgia: a structured programme better than corticosteroids and NSAID. *Scand J Occup Ther*. Sep 2012;19(5):404-410.
31. Berglund K, Perrson B, Denison E. Prevalence of pain and dysfunction in the cervical and thoracic spine in persons with and without lateral elbow pain. *Manual Therapy*. 2008;13(4):295 - 299.
32. Fernandez-Carnero J, Fernandez-de-las-Penas C, Cleland JA. Immediate hypoalgesic and motor effects after a single cervical spine manipulation in subjects with lateral epicondylalgia. *J Manipulative Physiol Ther*. Nov-Dec 2008;31(9):675-681.
33. Fernandez-Carnero J, Cleland JA, Arbizu RL. Examination of motor and hypoalgesic effects of cervical vs thoracic spine manipulation in patients with lateral epicondylalgia: a clinical trial. *J Manipulative Physiol Ther*. Sep 2011;34(7):432-440.
34. Laban MM, Iyer R, Tamler MS. Occult periarthrosis of the shoulder: a possible progenitor of tennis elbow. *Am J Phys Med Rehabil*. Nov 2005;84(11):895-898.
35. Alizadehkhayat O, Fisher AC, Kemp GJ, Vishwanathan K, Frostick SP. Upper limb muscle imbalance in tennis elbow: a functional and electromyographic assessment. *J Orthop Res*. Dec 2007;25(12):1651-1657.

36. Alizadehkhayat O, Fisher AC, Kemp GJ, Frostick SP. Strength and fatigability of selected muscles in upper limb: assessing muscle imbalance relevant to tennis elbow. *J Electromyogr Kinesiol.* Aug 2007;17(4):428-436.
37. Lucado AM, al e. Subacromial impingement syndrome and lateral epicondylalgia in tennis players. *Physical Therapy Reviews.* 2010;15(2):55-61.
38. Alizadehkhayat O, Fisher AC, Kemp GJ, Vishwanathan K, Frostick SP. Assessment of functional recovery in tennis elbow. *J Electromyogr Kinesiol.* Aug 2009;19(4):631-638.
39. Lucado AM, Kolber MJ, Cheng MS, Echternach JL, Sr. Upper extremity strength characteristics in female recreational tennis players with and without lateral epicondylalgia. *J Orthop Sports Phys Ther.* Dec 2012;42(12):1025-1031.
40. Hidetomo S, al e. Alterations in Upper Extremity Motion After Scapular-Muscle Fatigue. *Journal of Sport Rehabilitation.* 2006;15:71-88.
41. Samani A, Fernandez-Carnero J, Arendt-Nielsen L, Madeleine P. Interactive effects of acute experimental pain in trapezius and sore wrist extensor on the electromyography of the forearm muscles during computer work. *Appl Ergon.* Jul 2011;42(5):735-740.
42. McClure P, Tate AR, Kareha S, Irwin D, Zlupko E. A clinical method for identifying scapular dyskinesis, part 1: reliability. *J Athl Train.* Mar-Apr 2009;44(2):160-164.
43. Michener LA, Boardman ND, Pidcoe PE, Frith AM. Scapular muscle tests in subjects with shoulder pain and functional loss: reliability and construct validity. *Phys Ther.* Nov 2005;85(11):1128-1138.
44. Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA. Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. *J Athl Train.* Mar-Apr 2012;47(2):149-158.
45. Johnson EG, Godges JJ, Lohman EB, Stephens JA, Zimmerman GJ, Anderson SP. Disability self-assessment and upper quarter muscle balance between female dental hygienists and non-dental hygienists. *J Dent Hyg.* Fall 2003;77(4):217-223.
46. Wang SS, Normile SO, Lawshe BT. Reliability and smallest detectable change determination for serratus anterior muscle strength and endurance tests. *Physiother Theory Pract.* Jan 2006;22(1):33-42.
47. Cortez PJ, Tomazini JE, Valenti VE, Correa JR, Valenti EE, Abreu LC. A new device to measure isometric strength in upper limbs: comparison between dominant and non-dominant limbs. *Clinics (Sao Paulo).* 2011;66(2):351-354.
48. Turner N, Ferguson K, Mobley BW, Riemann B, Davies G. Establishing normative data on scapulothoracic musculature using handheld dynamometry. *J Sport Rehabil.* Nov 2009;18(4):502-520.
49. O'Sullivan C, Bentman S, Bennett K, Stokes M. Rehabilitative ultrasound imaging of the lower trapezius muscle: technical description and reliability. *J Orthop Sports Phys Ther.* Oct 2007;37(10):620-626.
50. Sipila S, Suominen H. Quantitative ultrasonography of muscle: detection of adaptations to training in elderly women. *Arch Phys Med Rehabil.* Nov 1996;77(11):1173-1178.
51. Miyatani M, Kanehisa H, Fukunaga T. Validity of bioelectrical impedance and ultrasonographic methods for estimating the muscle volume of the upper arm. *Eur J Appl Physiol.* Aug 2000;82(5-6):391-396.
52. Kiesel KB, Uhl TL, Underwood FB, Rodd DW, Nitz AJ. Measurement of lumbar multifidus muscle contraction with rehabilitative ultrasound imaging. *Man Ther.* May 2007;12(2):161-166.

53. Mannion AF, Pulkovski N, Gubler D, et al. Muscle thickness changes during abdominal hollowing: an assessment of between-day measurement error in controls and patients with chronic low back pain. *Eur Spine J.* Apr 2008;17(4):494-501.
54. O'Sullivan C, Meaney J, Boyle G, Gormley J, Stokes M. The validity of Rehabilitative Ultrasound Imaging for measurement of trapezius muscle thickness. *Man Ther.* Oct 2009;14(5):572-578.
55. Phadke V, Camargo P, Ludewig P. Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. *Rev Bras Fisioter.* Feb 1 2009;13(1):1-9.
56. O'Sullivan C, McCarthy Persson U, Blake C, Stokes M. Rehabilitative ultrasound measurement of trapezius muscle contractile states in people with mild shoulder pain. *Man Ther.* Apr 2012;17(2):139-144.
57. The New Investigator Award. *Journal of Athletic Training.* 2012;47 (3 (Suppliment)):S7-S8.
58. Ando R, Arai T, Beppu M, Hirata K, Takagi M. Anatomical study of arthroscopic surgery for lateral epicondylitis. *Hand Surg.* 2008;13(2):85-91.
59. Wood W, Stewart A, Bell-Jenge T. LATERAL EPICONDYLALGIA: AN OVERVIEW. *Physical Therapy Reviews.* 2006;11:155-160.
60. Barr S, Cerisola FL, Blanchard V. Effectiveness of corticosteroid injections compared with physiotherapeutic interventions for lateral epicondylitis: a systematic review. *Physiotherapy.* Dec 2009;95(4):251-265.
61. Smidt N, Assendelft WJ, van der Windt DA, Hay EM, Buchbinder R, Bouter LM. Corticosteroid injections for lateral epicondylitis: a systematic review. *Pain.* Mar 2002;96(1-2):23-40.
62. Kalichman L, Bannuru RR, Severin M, Harvey W. Injection of botulinum toxin for treatment of chronic lateral epicondylitis: systematic review and meta-analysis. *Semin Arthritis Rheum.* Jun 2011;40(6):532-538.
63. Smidt N, van der Windt DA, Assendelft WJ, Deville WL, Korthals-de Bos IB, Bouter LM. Corticosteroid injections, physiotherapy, or a wait-and-see policy for lateral epicondylitis: a randomised controlled trial. *Lancet.* Feb 23 2002;359(9307):657-662.
64. Kohia M, Brackle J, Byrd K, Jennings A, Murray W, Wilfong E. Effectiveness of physical therapy treatments on lateral epicondylitis. *J Sport Rehabil.* May 2008;17(2):119-136.
65. Borkholder CD, Hill VA, Fess EE. The efficacy of splinting for lateral epicondylitis: a systematic review. *J Hand Ther.* Apr-Jun 2004;17(2):181-199.
66. Raman J, MacDermid JC, Grewal R. Effectiveness of different methods of resistance exercises in lateral epicondylitis--a systematic review. *J Hand Ther.* Jan-Mar 2012;25(1):5-25; quiz 26.
67. Herd CR, Meserve BB. A systematic review of the effectiveness of manipulative therapy in treating lateral epicondylalgia. *J Man Manip Ther.* 2008;16(4):225-237.
68. Gonzalez-Iglesias J, Cleland JA, del Rosario Gutierrez-Vega M, Fernandez-de-las-Penas C. Multimodal management of lateral epicondylalgia in rock climbers: a prospective case series. *J Manipulative Physiol Ther.* Nov 2011;34(9):635-642.
69. Hansson GA, Balogh I, Ohlsson K, Palsson B, Rylander L, Skerfving S. Impact of physical exposure on neck and upper limb disorders in female workers. *Appl Ergon.* Jun 2000;31(3):301-310.
70. Ellenbecker TS, Pieczynski TE, Davies GJ. Rehabilitation of the elbow following sports injury. *Clin Sports Med.* Jan 2010;29(1):33-60, table of contents.

71. Ellenbecker TS, Reinold M, Nelson CO. Clinical concepts for treatment of the elbow in the adolescent overhead athlete. *Clin Sports Med*. Oct 2010;29(4):705-724.
72. Rlce S. Using the Kinetic Chain Theory in Clinical Practice. *Current Sports Medicine Reports*. 2003;2:289-290.
73. Putnam CA. Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *J Biomech*. 1993;26 Suppl 1:125-135.
74. Feltner ME, Bishop EJ, Perez CM. Segmental and kinetic contributions in vertical jumps performed with and without an arm swing. *Res Q Exerc Sport*. Sep 2004;75(3):216-230.
75. Feltner ME, Dapena J. Three-dimensional interactions in a two-segment kinetic chain, part 1: general model. *International Journal of Sports Biomechanics*. 1989;5:403-419.
76. Sciascia A, Cromwell R. Kinetic chain rehabilitation: a theoretical framework. *Rehabil Res Pract*. 2012;2012:853037.
77. Kreighbaurn E, Barthels K. *Throwlike and pushlike movement patterns In: Biomechanics , A qualitative approach to studying human movement*. 4th ed. Boston, MA: Allyn and Bacon; 1996.
78. Hodges PW, CA R. Feedforward contraction of transversus abdominus is not influenced by the direction of arm movement. *Experimental Brain Research* 1997;114:362-370.
79. Gurfinkel VS, Lipshits MI, Lestienne FG. Anticipatory neck muscle activity associated with rapid arm movements. *Neurosci Lett*. Nov 22 1988;94(1-2):104-108.
80. Hodges P, Cresswell A, Thorstensson A. Preparatory trunk motion accompanies rapid upper limb movement. *Exp Brain Res*. Jan 1999;124(1):69-79.
81. Falla D, Jull GA, Hodges P. Feedforward Activity of the Deep Cervical Flexors During Voluntary Arm Movements is Delayed in Patients with Chronic Neck Pain. 2004;2004(157):43-48.
82. Kinematic and Electromyographic Study of the Nocioceptive Withdrawel Reflex in the Upper Limbs During Rest and Movement. *Journal of Neuroscience*. 2006;26(13):3505 - 3512.
83. Vandenberghe A, Levin O, De Schutter J, Swinnen S, Jonkers I. Three-dimensional reaching tasks: effect of reaching height and width on upper limb kinematics and muscle activity. *Gait Posture*. Oct 2010;32(4):500-507.
84. Hirashima M, Kadota H, Sakurai S, Kudo K, Ohtsuki T. Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing. *J Sports Sci*. Apr 2002;20(4):301-310.
85. Sabatini AM. Identification of neuromuscular synergies in natural upper-arm movements. *Biol Cybern*. Apr 2002;86(4):253-262.
86. Martelloni C, Carpaneto J, Micera S. Characterization of EMG patterns from proximal arm muscles during object- and orientation-specific grasps. *IEEE Trans Biomed Eng*. Oct 2009;56(10):2529-2536.
87. Alizadehkhayat O, Fisher AC, Kemp GJ, Vishwanathan K, Frostick SP. Shoulder muscle activation and fatigue during a controlled forceful hand grip task. *J Electromyogr Kinesiol*. Jun 2011;21(3):478-482.
88. Mandalidis, Dimitris, O'Brien, Moira. Relationship between hand-grip isometric strength and isokinetic moment data of the shoulder stabilisers. *Journal of Bodywork & Movement Therapies*. 2010;14(1):19-26.
89. Nascimento LR, Polese JC, Faria CD, Teixeira-Salmela LF. Isometric hand grip strength correlated with isokinetic data of the shoulder stabilizers in individuals with chronic stroke. *J Bodyw Mov Ther*. Jul 2012;16(3):275-280.

90. Bolzoni F, Bruttini C, Esposti R, Cavallari P. Hand immobilization affects arm and shoulder postural control. *Exp Brain Res*. May 23 2012.
91. Naider-Steinhart S, Katz-Leurer M. Analysis of proximal and distal muscle activity during handwriting tasks. *Am J Occup Ther*. Jul-Aug 2007;61(4):392-398.
92. Genetic associations between frozen shoulder and tennis elbow: a female twin study. *Rheumatology* 2003;42:739-742.
93. Wong CK, Coleman D, diPersia V, Song J, Wright D. The effects of manual treatment on rounded-shoulder posture, and associated muscle strength. *J Bodyw Mov Ther*. Oct 2010;14(4):326-333.
94. Kebaetse M, McClure P, Pratt NA. Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics. *Arch Phys Med Rehabil*. Aug 1999;80(8):945-950.
95. Petersen SM, Wyatt SN. Lower trapezius muscle strength in individuals with unilateral neck pain. *J Orthop Sports Phys Ther*. Apr 2011;41(4):260-265.
96. Helgadottir H, Kristjansson E, Einarsson E, Karduna A, Jonsson H, Jr. Altered activity of the serratus anterior during unilateral arm elevation in patients with cervical disorders. *J Electromyogr Kinesiol*. Dec 2011;21(6):947-953.
97. Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. *J Orthop Sports Phys Ther*. Oct 1999;29(10):574-583; discussion 584-576.
98. Fayad F, Roby-Brami A, Gautheron V, et al. Relationship of glenohumeral elevation and 3-dimensional scapular kinematics with disability in patients with shoulder disorders. *J Rehabil Med*. Jun 2008;40(6):456-460.
99. Hardwick D, Lang C. Scapula and humeral movement patterns and their relationship with pain: a preliminary investigation. *International Journal of Therapy and Rehabilitation*. 2011;18(4):210-220.
100. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther*. Feb 2009;39(2):90-104.
101. MacDermid JC, Ramos J, Drosdowech D, Faber K, Patterson S. The impact of rotator cuff pathology on isometric and isokinetic strength, function, and quality of life. *J Shoulder Elbow Surg*. Nov-Dec 2004;13(6):593-598.
102. Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. *Br J Sports Med*. Apr 2010;44(5):319-327.
103. Pascarelli EF, Hsu YP. Understanding work-related upper extremity disorders: clinical findings in 485 computer users, musicians, and others. *J Occup Rehabil*. Mar 2001;11(1):1-21.
104. Keir PJ, Wells RP. The effect of typing posture on wrist extensor muscle loading. *Hum Factors*. Fall 2002;44(3):392-403.
105. Shimose R, Matsunaga A, Muro M. Effect of submaximal isometric wrist extension training on grip strength. *Eur J Appl Physiol*. Mar 2011;111(3):557-565.
106. Hale R, Dorman D, Gonzalez RV. Individual muscle force parameters and fiber operating ranges for elbow flexion-extension and forearm pronation-supination. *J Biomech*. Feb 24 2011;44(4):650-656.
107. Blackwell JR, Cole KJ. Wrist kinematics differ in expert and novice tennis players performing the backhand stroke: implications for tennis elbow. *J Biomech*. May 1994;27(5):509-516.

108. Dimberg L. The prevalence and causation of tennis elbow (lateral humeral epicondylitis) in a population of workers in an engineering industry. *Ergonomics*. Mar 1987;30(3):573-579.
109. Kivi P. The etiology and conservative treatment of humeral epicondylitis. *Scand J Rehabil Med*. 1983;15(1):37-41.
110. Maylack FH. Epidemiology of tennis, squash, and racquetball injuries. *Clin Sports Med*. Apr 1988;7(2):233-243.
111. Nirschl RP. Elbow tendinosis/tennis elbow. *Clin Sports Med*. Oct 1992;11(4):851-870.
112. Trudel D, Duley J, Zastrow I, Kerr EW, Davidson R, MacDermid JC. Rehabilitation for patients with lateral epicondylitis: a systematic review. *J Hand Ther*. Apr-Jun 2004;17(2):243-266.
113. Roto P, Kivi P. Prevalence of epicondylitis and tenosynovitis among meatcutters. *Scand J Work Environ Health*. Jun 1984;10(3):203-205.
114. Mottram SL. Dynamic stability of the scapula. *Man Ther*. Aug 1997;2(3):123-131.
115. Liemohn WP, Baumgartner TA, Gagnon LH. Measuring core stability. *J Strength Cond Res*. Aug 2005;19(3):583-586.
116. Wadsworth CT, Krishnan R, Sear M, Harrold J, Nielsen DH. Intrarater reliability of manual muscle testing and hand-held dynamometric muscle testing. *Phys Ther*. Sep 1987;67(9):1342-1347.
117. Hayes K, Walton JR, Szomor ZL, Murrell GA. Reliability of 3 methods for assessing shoulder strength. *Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons ... [et al]*. Jan-Feb 2002;11(1):33-39.
118. Cools AM, Geeroms E, Van den Berghe DF, Cambier DC, Witvrouw EE. Isokinetic scapular muscle performance in young elite gymnasts. *J Athl Train*. Oct-Dec 2007;42(4):458-463.
119. Cools AM, Witvrouw EE, Mahieu NN, Danneels LA. Isokinetic Scapular Muscle Performance in Overhead Athletes With and Without Impingement Symptoms. *J Athl Train*. Jun 2005;40(2):104-110.
120. Celik D, Sirmen B, Demirhan M. The relationship of muscle strength and pain in subacromial impingement syndrome. *Acta Orthop Traumatol Turc*. 2011;45(2):79-84.
121. Edmondston SJ, Wallumrod ME, Macleid F, Kvamme LS, Joebges S, Brabham GC. Reliability of isometric muscle endurance tests in subjects with postural neck pain. *J Manipulative Physiol Ther*. Jun 2008;31(5):348-354.
122. Saltin B, Sjogaard G, Gaffney FA, Rowell LB. Potassium, lactate, and water fluxes in human quadriceps muscle during static contractions. *Circ Res*. Jun 1981;48(6 Pt 2):118-24.
123. Edwards RH, Hill DK, McDonnell M. Myothermal and intramuscular pressure measurements during isometric contractions of the human quadriceps muscle. *J Physiol*. Jul 1972;224(2):58P-59P.
124. Sadamoto T, Bonde-Petersen F, Suzuki Y. Skeletal muscle tension, flow, pressure, and EMG during sustained isometric contractions in humans. *Eur J Appl Physiol Occup Physiol*. 1983;51(3):395-408.
125. McDermott MM, Tian L, Ferrucci L, et al. Associations between lower extremity ischemia, upper and lower extremity strength, and functional impairment with peripheral arterial disease. *J Am Geriatr Soc*. Apr 2008;56(4):724-729.
126. Smeele KM, Eerbeek O, Schaart G, et al. Reduced hexokinase II impairs muscle function 2 wk after ischemia-reperfusion through increased cell necrosis and fibrosis. *J Appl Physiol*. Aug 15 2012;113(4):608-618.

127. Inani SB, Selkar SP. Effect of core stabilization exercises versus conventional exercises on pain and functional status in patients with non-specific low back pain: A randomized clinical trial. *J Back Musculoskelet Rehabil.* Jan 1 2013;26(1):37-43.
128. Balthazard P, de Goumoens P, Rivier G, Demeulenaere P, Ballabeni P, Deriaz O. Manual therapy followed by specific active exercises versus a placebo followed by specific active exercises on the improvement of functional disability in patients with chronic non specific low back pain: a randomized controlled trial. *BMC Musculoskelet Disord.* 2012;13:162.
129. Singh MA. Exercise to prevent and treat functional disability. *Clin Geriatr Med.* Aug 2002;18(3):431-462, vi-vii.
130. Deones VL, Wiley SC, Worrell T. Assessment of quadriceps muscle performance by a hand-held dynamometer and an isokinetic dynamometer. *J Orthop Sports Phys Ther.* Dec 1994;20(6):296-301.
131. Hides JA, Richardson CA, Jull GA. Magnetic resonance imaging and ultrasonography of the lumbar multifidus muscle. Comparison of two different modalities. *Spine (Phila Pa 1976).* Jan 1 1995;20(1):54-58.
132. Hides J, Wilson S, Stanton W, al e. An MRI investigation into the function of the transverses abdominis muscle during “drawing-in” of the abdominal wall. *Spine.* 2006;31:E175-178.
133. Freilich RJ, Kirsner RL, Byrne E. Isometric strength and thickness relationships in human quadriceps muscle. *Neuromuscul Disord.* Sep 1995;5(5):415-422.
134. Hides JA, al e. Retraining motor control of abdominal muscles among elite cricketers with low back pain *Scandinavian Journal of Medicine & Science in Sports* 2009;20(6):834 - 843.
135. Vasseljen O, Fladmark AM. Abdominal muscle contraction thickness and function after specific and general exercises: a randomized controlled trial in chronic low back pain patients. *Man Ther.* Oct 2010;15(5):482-489.
136. Miyatani M, Kanehisa H, Kuno S, Nishijima T, Fukunaga T. Validity of ultrasonograph muscle thickness measurements for estimating muscle volume of knee extensors in humans. *Eur J Appl Physiol.* Jan 2002;86(3):203-208.
137. Reeves ND, Maganaris CN, Narici MV. Ultrasonographic assessment of human skeletal muscle size. *Eur J Appl Physiol.* Jan 2004;91(1):116-118.
138. Stokes M, Rankin G, Newham DJ. Ultrasound imaging of lumbar multifidus muscle: normal reference ranges for measurements and practical guidance on the technique. *Man Ther.* May 2005;10(2):116-126.
139. Esformes JI, Narici MV, Maganaris CN. Measurement of human muscle volume using ultrasonography. *Eur J Appl Physiol.* May 2002;87(1):90-92.
140. Hodges PW, Pengel LH, Herbert RD, Gandevia SC. Measurement of muscle contraction with ultrasound imaging. *Muscle Nerve.* Jun 2003;27(6):682-692.
141. Forthomme B, Crielaard JM, Croisier JL. Scapular positioning in athlete's shoulder : particularities, clinical measurements and implications. *Sports Med.* 2008;38(5):369-386.
142. Lucado AM. Scapular Muscle Imbalance: Implications for Shoulder Pain and Pathology. *Physical Therapy Reviews.* 2011.16 (5):356- 364.
143. Wang CY, Olson SL, Protas EJ. Test-retest strength reliability: hand-held dynamometry in community-dwelling elderly fallers. *Arch Phys Med Rehabil.* Jun 2002;83(6):811-815.
144. Teyhen DS. Rehabilitative ultrasound imaging for assessment and treatment of musculoskeletal conditions. *Man Ther.* Feb 2011;16(1):44-45.

145. Chi-Fishman G, Hicks JE, Cintas HM, Sonies BC, Gerber LH. Ultrasound imaging distinguishes between normal and weak muscle. *Arch Phys Med Rehab.* Jun 2004;85(6):980-986.
146. Bakke M, Tuxen A, Vilmann P, Jensen BR, Vilmann A, Toft M. Ultrasound image of human masseter muscle related to bite force, electromyography, facial morphology, and occlusal factors. *Scand J Dent Res.* Jun 1992;100(3):164-171.
147. Cuadros CL, Driscoll CL, Rothkopf DM. The anatomy of the lower serratus anterior muscle: a fresh cadaver study. *Plast Reconstr Surg.* Jan 1995;95(1):93-97; discussion 98-99.
148. Park SY, Yoo WG. Differential activation of parts of the serratus anterior muscle during push-up variations on stable and unstable bases of support. *J Electromyogr Kinesiol.* Oct 2011;21(5):861-867.
149. Lynch SS, Thigpen CA, Mihalik JP, Prentice WE, Padua D. The effects of an exercise intervention on forward head and rounded shoulder postures in elite swimmers. *Br J Sports Med.* Apr 2010;44(5):376-381.
150. Basmajian JV, Blumenstein R. *Biofeedback Principles and Practice for Clinicians* Baltimore: Williams and Wilkins; 1989.
151. Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. *Sports Med.* 2009;39(8):663-685.
152. Robertson DGE, Caldwell G, Hamill J, Kamen G, Whittllesey SN. *Research Methods in Biomechanics.* Champaign, IL: Human Kinetics; 2004.
153. Koppenhaver SL, Parent EC, Teyhen DS, Hebert JJ, Fritz JM. The effect of averaging multiple trials on measurement error during ultrasound imaging of transversus abdominis and lumbar multifidus muscles in individuals with low back pain. *J Orthop Sports Phys Ther.* Aug 2009;39(8):604-611.
154. Wattanaprakornkul D, Halaki M, Boettcher C, Cathers I, Ginn KA. A comprehensive analysis of muscle recruitment patterns during shoulder flexion: an electromyographic study. *Clin Anat.* Jul 2011;24(5):619-626.
155. Delaney S, Worsley P, Warner M, Taylor M, Stokes M. Assessing contractile ability of the quadriceps muscle using ultrasound imaging. *Muscle Nerve.* Oct 2010;42(4):530-538.
156. Moreau NG, Simpson KN, Teefey SA, Damiano DL. Muscle architecture predicts maximum strength and is related to activity levels in cerebral palsy. *Phys Ther.* Nov 2010;90(11):1619-1630.
157. Whittaker JL, Stokes M. Ultrasound imaging and muscle function. *J Orthop Sports Phys Ther.* Aug 2011;41(8):572-580.
158. Whittaker JL, Teyhen DS, Elliott JM, et al. Rehabilitative ultrasound imaging: understanding the technology and its applications. *J Orthop Sports Phys Ther.* Aug 2007;37(8):434-449.
159. Springer BA, Mielcarek BJ, Nesfield TK, Teyhen DS. Relationships among lateral abdominal muscles, gender, body mass index, and hand dominance. *J Orthop Sport Phys.* May 2006;36(5):289-297.
160. Rankin G, Stokes M, Newham DJ. Size and shape of the posterior neck muscles measured by ultrasound imaging: normal values in males and females of different ages. *Man Ther.* May 2005;10(2):108-115.
161. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther.* Mar 2000;80(3):276-291.

162. Rundquist PJ, Dumit M, Hartley J, Schultz K, Finley MA. Three-dimensional shoulder complex kinematics in individuals with upper extremity impairment from chronic stroke. *Disabil Rehabil.* 2012;34(5):402-407.
163. Rundquist PJ, Obrecht C, Woodruff L. Three-dimensional shoulder kinematics to complete activities of daily living. *Am J Phys Med Rehabil.* Aug 2009;88(8):623-629.
164. Ludewig PM, Cook TM, DA N. Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. *J Orthop Sports Phys Ther.* 1996;24:57-65.
165. Moseley JB, Jr., Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. *Am J Sports Med.* Mar-Apr 1992;20(2):128-134.
166. Szucs K, Navalgund A, Borstad JD. Scapular muscle activation and co-activation following a fatigue task. *Med Biol Eng Comput.* May 2009;47(5):487-495.
167. Clerke A, Clerke J. A literature review of the effect of handedness on isometric grip strength differences of the left and right hands. *Am J Occup Ther.* Mar-Apr 2001;55(2):206-211.
168. Demura S, Miyaguchi K, Aoki H. The difference in output properties between dominant and nondominant limbs as measured by various muscle function tests. *J Strength Cond Res.* Oct 2010;24(10):2816-2820.
169. Gallagher MA, Cuomo F, Polonsky L, Berliner K, Zuckerman JD. Effects of age, testing speed, and arm dominance on isokinetic strength of the elbow. *J Shoulder Elbow Surg.* Jul-Aug 1997;6(4):340-346.
170. Wang HK, Macfarlane A, Cochrane T. Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *Br J Sports Med.* Feb 2000;34(1):39-43.
171. Hughes RE, Johnson ME, O'Driscoll SW, An KN. Normative values of agonist-antagonist shoulder strength ratios of adults aged 20 to 78 years. *Arch Phys Med Rehabil.* Oct 1999;80(10):1324-1326.
172. Mulligan IJ, Biddington WB, Barnhart BD, Ellenbecker TS. Isokinetic profile of shoulder internal and external rotators of high school aged baseball pitchers. *J Strength Cond Res.* Nov 2004;18(4):861-866.
173. Alfredson H, Pietila T, Lorentzon R. Concentric and eccentric shoulder and elbow muscle strength in female volleyball players and non-active females. *Scand J Med Sci Sports.* Oct 1998;8(5 Pt 1):265-270.
174. Cools AM, Dewitte V, Lanszweert F, et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? *Am J Sports Med.* Oct 2007;35(10):1744-1751.
175. Ekstrom RA, Donatelli RA, Soderberg GL. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. *J Orthop Sports Phys Ther.* May 2003;33(5):247-258.
176. Hunsaker F, Cioffi D, Amadio P, Wright J, Caughlin B. The American academy of orthopaedic surgeons outcomes instruments: normative values from the general population. *Journal of Bone Joint Surgery.* 2002;84A(2):208-215.
177. Brophy RH, Beauvais RL, Jones EC, Cordasco FA, Marx RG. Measurement of shoulder activity level. *Clin Orthop Relat Res.* Oct 2005;439:101-108.
178. Dictionary of Occupational Titles. <http://www.occupationalinfo.org/index.html>.
179. Stull GA, Clarke DH. Patterns of recovery following isometric and isotonic strength decrement. *Med Sci Sports.* Fall 1971;3(3):135-139.

180. Petrofsky JS. Quantification through the surface EMG of muscle fatigue and recovery during successive isometric contractions. *Aviat Space Environ Med.* Sep 1981;52(9):545-550.
181. Celik D, Dirican A, Baltaci G. Intrarater reliability of assessing strength of the shoulder and scapular muscles. *J Sport Rehabil.* 2012;Technical Notes 3:1-5.
182. Abulencia A, Acosta D, Adelman J, et al. Measurement of the tt production cross section in pp collisions at square root s = 1.96 TeV using missing E(T) + jets events with secondary vertex b tagging. *Phys Rev Lett.* May 26 2006;96(20):202002.
183. Cools AM, Johansson FR, Cambier DC, Velde AV, Palmans T, Witvrouw EE. Descriptive profile of scapulothoracic position, strength and flexibility variables in adolescent elite tennis players. *Br J Sports Med.* Jul 2010;44(9):678-684.
184. Murray MP, Gore DR, Gardner GM, Mollinger LA. Shoulder motion and muscle strength of normal men and women in two age groups. *Clin Orthop Relat Res.* Jan-Feb 1985(192):268-273.
185. Brotons-Gil E, Garcia-Vaquero MP, Peco-Gonzalez N, Vera-Garcia FJ. Flexion-Rotation Trunk Test to Assess Abdominal Muscle Endurance: Reliability, Learning Effect and Sex Differences. *J Strength Cond Res.* Sep 21 2012.
186. Ekstrom RA, Osborn RW, Hauer PL. Surface electromyographic analysis of the low back muscles during rehabilitation exercises. *J Orthop Sports Phys Ther.* Dec 2008;38(12):736-745.
187. Farina D, Kallenberg LA, Merletti R, Hermens HJ. Effect of side dominance on myoelectric manifestations of muscle fatigue in the human upper trapezius muscle. *Eur J Appl Physiol.* Nov 2003;90(5-6):480-488.
188. Lahz JR. Pathology and treatment of tennis elbow. *J Bone Joint Surg Br.* Feb 1948;30B(1):223.
189. Bisset L, Beller E, Jull G, Brooks P, Darnell R, Vicenzino B. Mobilisation with movement and exercise, corticosteroid injection, or wait and see for tennis elbow: randomised trial. *BMJ.* Nov 4 2006;333(7575):939.
190. Hunsaker FG, Cioffi DA, Amadio PC, Wright JG, Caughlin B. The American academy of orthopaedic surgeons outcomes instruments: normative values from the general population. *J Bone Joint Surg Am.* Feb 2002;84-A(2):208-215.
191. Suzuki N, Endo S. A quantitative study of trunk muscle strength and fatigability in the low-back-pain syndrome. *Spine (Phila Pa 1976).* Jan-Feb 1983;8(1):69-74.
192. Ito T, Shirado O, Suzuki H, Takahashi M, Kaneda K, Strax TE. Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. *Arch Phys Med Rehabil.* Jan 1996;77(1):75-79.
193. Minning S, Eliot CA, Uhl TL, Malone TR. EMG analysis of shoulder muscle fatigue during resisted isometric shoulder elevation. *J Electromyogr Kinesiol.* Apr 2007;17(2):153-159.
194. Thigpen CA, Padua DA, Michener LA, et al. Head and shoulder posture affect scapular mechanics and muscle activity in overhead tasks. *J Electromyogr Kinesiol.* Aug 2010;20(4):701-709.
195. Weon JH, Oh JS, Cynn HS, Kim YW, Kwon OY, Yi CH. Influence of forward head posture on scapular upward rotators during isometric shoulder flexion. *J Bodyw Mov Ther.* Oct 2010;14(4):367-374.
196. Bray SR, Martin Ginis KA, Woodgate J. Self-regulatory strength depletion and muscle-endurance performance: a test of the limited-strength model in older adults. *J Aging Phys Act.* Jul 2011;19(3):177-188.

Vita

Joseph Matthew Day MSPT, OCS, CIMT

Certificate or Specialty Board Licensure:

Kentucky Licensed Physical Therapist # PT004642 (2004-2007) and (2010-present)
Ohio Licensed Physical Therapist #096.002502 (2007-2010)
Orthopedic Certified Specialist (since 2007)
Certified Integrated Manual Therapist (since 2009)
Graduate Certificate in College Teaching and Learning, University of Kentucky

I. Education

- 2009-present University of Kentucky, Lexington, KY
Doctoral Candidate, Rehabilitation Science (Ph.D.),
College of Health Sciences
Dissertation: Scapular Muscle Performance in Patients with Lateral Epicondylalgia
- 2001-2004 University of Kentucky, Lexington, KY
Master of Science, Physical Therapy
Thesis: The Effects of Positioning on Muscle Tone in Post Stroke Patients
- 1996-2000 Murray State University, Murray, KY
Bachelor of Science, Biology
Deans List 4 semesters, Magna cum Laude

II. Professional Experiences

- August 2010-present Research Assistant, Clinician, and Mentor
Kentucky Hand and Physical Therapy, Lexington, KY
- June 2006-July 2010 Clinician, Clinical Instructor, Clinical Director
Physiotherapy Associates, Jeffersonville, IN &
Lebanon/Centerville, OH
- August 2004-June 2006 Clinician
Physical therapy Specialists, Louisville, KY

III. Teaching Activity

- University of Kentucky
Spring 2013 PT 805: Functional Anatomy - Laboratory Assistant
Spring 2012 AT 690: Orthopedic Evaluation & Rehabilitation of the
Upper Extremity – Teaching Assistant

Fall 2011 PT 651: Dysfunction of Vertebral Joints – Teaching and Laboratory Assistant
Fall 2010- Spring 2011 PT 650: Peripheral Joint Dysfunction – Laboratory Assistant

University of Dayton

Spring 2010 DPT 988: Advanced Therapy II: Contemporary Practice Issues – Clinical Instructor

Ohio University

Spring 2009 PT8922: Clinical Practicum – Clinical Instructor

IV. Advising Activity

University of Kentucky

Spring 2012 KHP 577-Practicum for 2 students. Undergraduate Research in Health Sciences. Musculoskeletal Ultrasound Imaging.

Kentucky Hand and Physical Therapy

Fall 2002 – present Clinical Mentor for New Graduates

V. Service and Leadership Activity

2011-present Reviewer, Journal of Sport Rehabilitation
2010-present Musculoskeletal lab and Journal Club Participant
2009-2010 Pre-Cana Marriage Preparation Leader
2007-present APTA Orthopedic Section Member
2005-2006 Friends for Life
2003-2004 Student Ambassador - College of Health Sciences
2002-2003 Run for Your Life - Chairperson
2000-2001 Missionary High School Teacher in Jamaica, West Indies

VI. Speaking Engagements/Presentations

Peer Reviewed

April 2013 Center for Clinical and Translational Science Annual Conference, Lexington, KY

-Poster – *Thickness of the Lower Trapezius and Serratus Anterior Using Ultrasound Imaging During a Repeated Arm Lifting Task.*
Day JM, Uhl TL

January 2013 Combined Sections Meeting of the American Physical Therapy Association, San Diego, CA

-Platform Presentation- *Outcomes Following the Conservative Management of Patients with Non-radicular Peripheral Neuropathic Pain.* **Day JM, Uhl TL, G. Pitts, J. Willoughby, M. McCallum, R. Foister**

-Platform Presentation – *Thickness of the Lower Trapezius and Serratus Anterior Using Ultrasound Imaging During a Repeated Arm Lifting Task.* **Day JM, Uhl TL**

October 2012 University of Kentucky Center for Muscle Biology Annual Retreat, Lexington, KY

-Poster – *Thickness of the Lower Trapezius and Serratus Anterior Using Ultrasound Imaging During a Repeated Arm Lifting Task.* **Day JM, Uhl TL**

Invited

May 2011 University of Kentucky Muscle Forum
Lexington, KY

-Presentation – *Thickness of the Lower Trapezius and Serratus Anterior Using Ultrasound Imaging During a Repeated Arm Lifting Task.* **Day JM, Uhl TL**

VII. Research and Creative Productivity

Refereed Journal Publications

Day, Joseph M.; McKeon, Patrick; Nitz, Arthur; *The Efficacy of Cervical/Thoracic Active Range of Motion for Detecting Changes Associated with Individuals Receiving Muscle Energy Techniques.* Physical Therapy Reviews, 2010 Dec; 15 (6): 453-61

Day, Joseph M.; Nitz, Arthur; *The Effect of Muscle Energy Techniques on Disability and Pain Scores in Individuals with Low Back Pain.* Journal of Sport Rehabilitation, 2012 May; 21 (2): 194-98

Manuscripts in progress

Day JM, Uhl TL. *Thickness of the Lower Trapezius and Serratus Anterior Using Ultrasound Imaging During a Repeated Arm Lifting Task.* Manual Therapy.

Day JM, Uhl TL, G. Pitts, J. Willoughby, M. McCallum, R. Foister. *Outcomes Following the Conservative Management of Patients with Non-radicular Peripheral Neuropathic Pain.* Journal of Hand Therapy.

Day JM, Uhl TL, Nitz AJ, Stemple JC, Bush HM. *A Comparison of Dominant to Non-dominant Scapular Muscle Strength and Endurance in Healthy Individuals.*

Day JM, Uhl TL, Nitz AJ Stemple JC, Bush HM *Scapular Muscle Assessment in Patients with Lateral Epicondylalgia*