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Pre-Operative Versus Post-Operative Kinematic Assessment and Functional Outcomes of the Thoracohumeral Joint in Adults with Rotator Cuff Tears

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PRE- OPERATIVE VERSUS POST-OPERATIVE KINEMATIC ASSESSMENT AND FUNCTIONAL OUTCOMES OF THE THORACOHUMERAL JOINT IN ADULTS WITH ROTATOR CUFF TEARS

by

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ABSTRACT

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The University of Wisconsin-Milwaukee, 2018
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This project investigated upper extremity (UE) motion and functional outcomes before and after full-thickness supraspinatus rotator cuff (RC) repair through kinematic analyses of three Activities of Daily Living (ADL) tasks. RC repair is a standard procedure known to alleviate pain, weakness, and stiffness, with improvements of decreased pain and increased range of motion (ROM). Eight (8) subjects (63.6 ± 6.3) with a supraspinatus RC tear participated in this study. Three ADLs were recorded and analyzed at the UWM Mobility Lab using a 15 camera motion capture system. Shoulder health outcome scores (ASES) were taken at each session to determine patients' pain and perceived functionality of the surgical shoulder. Testing took place two times: 0-12 weeks prior to surgery and 9-12 weeks after surgery. There was not a significant difference of the thoracohumeral joint abduction/adduction ROM pre-to-post-operatively during the crossbody task ($P=0.012$). No differences in ROM pre-to-post-operatively of the surgical shoulder during the hair comb and reach to back pocket tasks may be due to capsular tightness occurring at the 3 month follow up window. Also, no difference between the surgical and non-surgical abduction/adduction ROM pre-operatively may be due to a wash out effect of the subjects due to tendon involvement. Subjects may need to be analyzed based on number of tendons involved due to the difference in ROM between group A and B. No change in ASES scores may be due to the follow up window being too soon in the rehabilitation process and should be investigated at a longer follow up window.

I would like to dedicate my thesis to my parents.

Without your guidance I would not be where I am today. Thank you for pushing me to reach great heights and be the best person I can be.

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LIST OF ABBREVIATIONS

AC	Acromioclavicular
ADL	Activities of Daily Living
AHD	Acromiohumeral Distance
AOTA	American Occupational Therapy Association
AROM	Active Range of Motion
ASES	American Shoulder and Elbow Surgeons shoulder assessment
CAT	Computerized Adaptive Testing
EMG	Electromyography
FIM	Functional Independence Measure
GH	Glenohumeral
ICF	International Classification of Functioning, Disability, and Health
OT	Occupational Therapy
PLOF	Prior Level of Function
PRO	Patient Reported Outcomes
PROM	Passive Range of Motion
SC	Sternoclavicular
ST	Scapulothoracic
TH	Thoracohumeral
UE	Upper Extremity
RC	Rotator Cuff
ROM	Range of Motion

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I. Introduction

Approximately one quarter of U.S. adults will have a rotator cuff (RC) tear in their lifetime, and about 300,000 RC repair surgeries are performed annually (Crawford, 2014). The supraspinatus is the most commonly torn rotator cuff muscle requiring surgical repair (Opsha et al., 2008). RC tears can impede physical function, such as one's ability to perform activities of daily living (ADLs), and maintain functional independence (Lin, Weintraub, & Aragaki, 2008; Walker-Bone, Palmer, Reading, Coggon, & Cooper, 2004). The American Occupational Therapy Association defines ADLs as the tasks of taking care of one's own body ("Occupational Therapy Practice framework: domain and process," 2014). The surgery is associated with improved function, and patient satisfaction with the goal of surgical repair is to decrease pain, increase range of motion (ROM), and allow return to the workforce (Day, Taylor, & Green, 2012; Nho et al., 2009). Although patients may be able to perform ADLs independently before surgery, they may be using altered kinematics due to injury and pain. While studies have compared post-operative thoracohumeral (humerus relative to thorax) joint kinematics of various populations, there is no known research assessing upper extremity (UE) joint kinematics of ADLs pre- and post-operatively, which may provide insight on the rehabilitation process. (Fritz et al., 2017; Vidt et al., 2016). The purpose of this study is to compare thoracohumeral (TH) joint kinematics of three ADLs and shoulder function before and after supraspinatus repair surgery. It is hypothesized that TH joint kinematics and functional shoulder outcomes will be significantly different following rotator cuff surgery.

Purpose

The purpose of this study is to quantify and compare TH joint kinematics during three ADL tasks before and after rotator cuff repair. The goal of this research study is to provide more information on TH joint kinematics comparing pre-to-post-operative function, surgical vs. nonsurgical shoulder function, and pre-to-post-operative functional outcomes scores. This knowledge may aide the healthcare team in deciding if surgery is appropriate based on pre-operative status and could give insight into effective progression for each patient to the optimal function of their surgical shoulder after surgery allowing for greater participation in meaningful activities. Quantifying ADL performance pre-to post would provide the healthcare team the knowledge to understand each patient's current ability, create an effective plan of care, and ultimately ensure better restoration of shoulder function after RC repair. Occupational Therapists could evaluate patients pre-operatively, establish baseline measurements, educate the patient on all aspects of the upcoming procedure, and transition them into a smooth recovery afterwards for optimal gains of the injured shoulder reducing the need for compensation strategies.

Hypothesis and Aims

Aim 1: Compare the surgical thoracohumeral joint range of motion before and after surgery

I will investigate TH joint ROM angles pre-and-post- operatively during the three ADLs.

Hypothesis A: The TH joint abduction/adduction ROM will be different pre-operatively compared to post-operatively for the combing task.

Hypothesis B: The TH joint internal/external rotation ROM will be different pre-operatively compared to post-operatively for the crossbody task.

Hypothesis C: The TH joint flexion/extension ROM will be different pre-operatively compared to post-operatively for the reach to back pocket task.

Aim 2: Identify thoracohumeral joint range of motion differences between surgical and non-surgical shoulder pre-operatively to quantify compensation strategies.

I will investigate TH joint abduction/adduction ROM between the surgical and non-surgical shoulder in the combing task.

Hypothesis 1: The surgical TH joint abduction/adduction ROM will be different from the non-surgical shoulder in the combing task.

Aim 3: Measure occupational performance before and after surgery using a valid clinical outcome tool of the American Shoulder and Elbow Surgeons (ASES) assessment.

The shoulder assessment, ASES, will be used to measure occupational performance.

Hypothesis 1: Subjects will have a significant difference in ASES scores between pre-and post-operative sessions.

Significance to Occupational Therapy

To fully engage in desired occupations such as ADLs, individuals require the use of their upper extremities. Reaching to back pocket, cross body, and combing hair simulate toilet care, dressing, and grooming, respectively. These are demanding activities of the shoulder. If the upper extremity is impaired, the ability to perform these occupations could be hindered limiting their participation. This study investigates occupational performance of people with full-thickness rotator cuff tears and their ability to perform ADLs. The AOTA Practice Framework (2014) expresses occupational performance as the act of accomplishing an action, activity, or occupation that results in a transaction between the client, activity, and context. Improving these skills usually leads to an increase in participation in occupations or activities. An orthopedic impairment, such as RC tear, can decrease performance skills. RC tears are common orthopedic condition occupational therapists treat with the goal of rehabilitating the upper extremity to prior level of function and promote occupational performance. An occupational therapist' role is to enable participation of meaningful activities when one has suffered from injury or disease. Occupational therapists analyze the meaningful occupations their clients wish to engage in and then determine the most feasible way of enabling participation. Factors, such as activity demands, client factors, and quality of life, influence whether a client can perform a task. These impact the individuals' ability or inability to execute performance skills. When one can perform their meaningful occupations, they would be classified as independent.

This study's overall aim is to investigate and quantify TH joint kinematics during the performance of ADLs before and after RC repair. This is the first step in understanding if patients are performing their ADLs differently before and after rotator cuff injury. Understanding if and how patients are moving differently may help to understand how patients are using compensatory strategies to complete ADLs. Knowing if and how they are compensating will allow the healthcare team to promote correct movements and encourage proper use of the UE. This will ultimately lead to a better performing UE with fewer complications after surgery. With this knowledge, patients with rotator cuff injury may have better outcomes of UE shoulder function without compensatory methods of completing ADLs. The motion capture tool used in this study may establish a baseline of function prior to surgery, giving insight to therapists on patients' abilities prior to surgery. Evaluating patients before surgery allows for the collection of objective measurements, such as ROM, strength, and ADL status, to transition the patient into a smoother post-operative recovery.

Shoulder Anatomy and Biomechanics

The shoulder complex is an intricate arrangement of bones, joints, nerves, and muscles that enable functional ROM of the upper extremity (UE). It is comprised of four articulations including the glenohumeral (GH), sternoclavicular (SC), acromioclavicular (AC), and scapulothoracic (ST) joints (Figure 1). The thoracohumeral joint (TH) can be defined as the summation of the four joints of the shoulder (GH+SC+AC+ST) and is defined by the biomechanical model as the humerus relative to the thorax. The shoulder complex sacrifices joint stability for mobility, thereby enhancing the position of the elbow, forearm, wrist, and hand for ADLs.

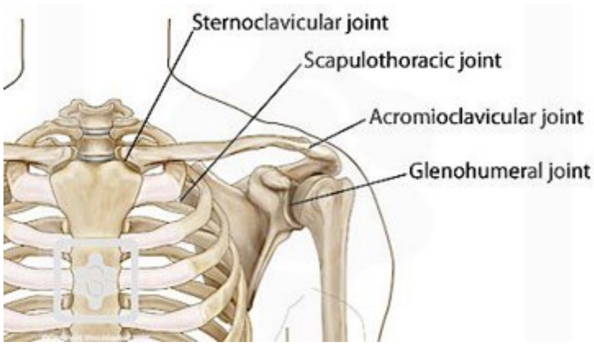

Figure 1. Shoulder joints

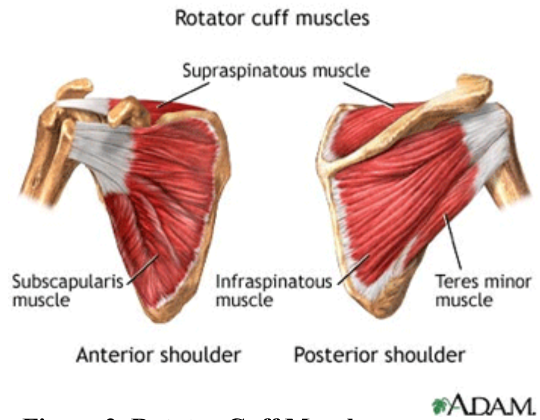

Figure 2. Rotator Cuff Muscles

The GH is the articulation of the humeral head and glenoid fossa of the scapula. The GH joint has three degrees of freedom and can perform flexion/extension (sagittal), abduction/adduction (coronal), and internal/external rotation (transverse). Available range of motion for flexion and extension around a medial-lateral axis is 120 degrees (could reach to 180 with scapula) and 45 to 55 degrees, respectively. Range of motion for abduction and adduction along an anterior-posterior axis of the GH joint is 120 degrees, but could reach 180 degrees with help from the scapula. Ranges for internal and external rotation occur around a longitudinal axis with 75 to 85 degrees and 60 to 70 degrees respectively from anatomical position (Neumann, 2017).

The SC joint is a saddle joint with the articulation of the sternum and medial end of the clavicle. It is responsible for holding the scapula at a constant distance from the trunk. The clavicle has three degrees of freedom and has ability to perform elevation/depression (coronal), protraction/retraction (transverse), and posterior rotation (sagittal). The range of motion available at the SC joint for elevation and depression are 45 degrees and 10 degrees, respectively.

Protraction and retraction have between 15 to 30 degrees of movement, while the SC allows 40 to50 degrees of posterior rotation. The main stabilizer of the SC joint includes the sternocleidomastoid muscle (Neumann, 2017).

The AC joint, comprised of the acromion process of the scapula and lateral end of the clavicle, is responsible for attaching the scapula to the clavicle. The acromion process extends anteriorly and laterally to create a horizontal edge over the glenoid fossa. The gliding joint allows for subtle movements of the scapula and has three degrees of freedom. Most commonly, the AC joint performs upward/downward rotation permitting about 30 degrees when the arm is rotated upwards. Other horizontal and sagittal plane rotational movements are allowed, but minuscule. These slight movements allow for optimal mobility at the ST joint. The deltoids and upper trapezius muscles help stabilize the AC joint (Neumann, 2017).

The ST joint is a pseudo joint as it is a point of contact between the anterior scapula and the thorax. These movements occur due to the collaboration of the SC and AC joints. The movements of the ST include elevation, depression, protraction, retraction, and upward and downward rotation. A fully upward rotated scapula allows for lifting the arm fully overhead and past 120 degrees. The SC accounts for about 60 degrees of shoulder abduction or flexion. When fully rotated, the scapula projects the glenoid fossa upward and anteriorly causing an optimal structural base for the humeral head to perform anterior and lateral reaching of the upper limb. It also protects the tension and length of the abductor muscles, such as middle deltoid and supraspinatus. A properly upward rotated scapula helps maintain the volume of the subacromial space, which is highly critical for the muscular tendons passing through this opening.

Dynamic stability is maintained through the shoulder complex via musculature known as the RC. Rathi, Taylor, and Green (2016) confirmed the rotator cuff functions as a GH joint stabilizer by limiting humeral head translation. The RC comprises four muscles: subscapularis, supraspinatus, infraspinatus, and teres minor (Figure 2). The subscapularis, located on the anterior surface of the scapula in the subscapular fossa, inserts on the lessor tubercle of the humerus. Subscapularis muscle activation results in internal rotation of the humerus. The supraspinatus is located within the supraspinatous fossa located superior to the spine of the scapula, passes through the GH joint capsule, and inserts on the anterior portion of the greater tubercle of the humerus. The supraspinatus muscle primarily performs shoulder abduction. Alenabi, Dal Maso, Tetreault, and Begon (2016) identified the supraspinatus as more active during shoulder abduction than scaption (a combination of abduction and flexion) or flexion and did not increase after 40 degrees of elevation. The infraspinatus is located inferiorly to the spine of the scapula within the infraspinatous fossa and inserts on the middle aspects of the greater tubercle of the humerus. The infraspinatus muscle is responsible for performing external rotation with the help of the teres minor. The teres minor is located on the posterior lateral border of the scapula and inserts on the posterior aspect of the greater tubercle of the humerus. Burkhart, Esch, and Jolson (1993) refer to two regions of the RC cuff as the rotator crescent and cable. The rotator crescent is a crescent shaped sheet comprising the distal portions of the supraspinatus and infraspinatus muscles. The rotator cable is a thick bundle of fibers that are perpendicular to the axis of tendon and arch anteriorly and posteriorly to attach on the humerus. It spans from the biceps brachii to the inferior margin of the infraspinatus. Burkhart et al. (1993) describes the rotator cable as a suspension bridge; When it is intact, the RC would be able to maintain shoulder strength and ROM even in the presence of a full-thickness tear. If the cable becomes compromised, the cuff will lose its main stabilizing structure, leading to worsening shoulder symptoms. Burkhart et al. (1993) found most tears occur within the crescent.

The scapula and four rotator cuff muscles' primary responsibilities are to help stabilize the humerus when in motion (Rathi et al., 2016). The RC muscles provide dynamic stability by balancing force couples of the GH joint in the coronal and transverse planes of motion. The inferior cuff, comprised of the infraspinatus, teres minor, and subscapularis, function to balance the superior moment created by the deltoid muscles in the coronal plane. The anterior cuff, comprised of the subscapularis, functions to balance the posterior moment created by the posterior cuff created by the infraspinatus and teres minor in the transverse plane. The balance of RC muscles maintains a stable fulcrum for GH motion.

Inman, deC. M. Saunders, and Abbott (1944) wrote GH joint abduction/flexion and scapular upward rotation occurs simultaneously and named this observation as scapulohumeral rhythm. After thirty degrees of abduction, the rhythm remains at a constant ratio of 2:1, meaning for every 3 degrees of abduction, 2 degrees occur by the GH joint abduction, and 1 degree of ST upward rotation (Neumann, 2017). There are three phases of shoulder flexion that is essential to perform functional tasks: initial, middle, and final phase (Neumann, 2017). During the initial stage (0-60 degrees), the GH primarily moves. The middle phase, or critical phase (60-140 degrees), primarily depends on glenohumeral and scapulothoracic movement. In the final stage (140-180 degrees) the GH primarily moves again. It is necessary to understand the phases of a basic shoulder movement to understand how scapular movement contributes to overhead GH movement.

The shoulder complex also comprises accessory muscles to help with arm motion. The deltoids, upper trapezius, and pectoralis major all play a role during overhead activities. The anterior, middle, and posterior deltoids assist in performing shoulder flexion, abduction, and extension, respectively. The anterior deltoid originates at the anterior surface of the lateral end of the clavicle. The middle deltoid origin is at the superior surface of the lateral edge of the acromion, and the posterior deltoid is on the posterior border of the spine of the scapula. The three sections of the deltoid insert on the deltoid tuberosity located on the humerus. The upper trapezius is proximally attached to the spinous processes and attaches distally to the posterior-superior edge of the lateral one-third of the clavicle. The pectoralis major has two proximal attachments on the anterior medial half of the clavicle and lateral margin of the manubrium and sternum. It distally attaches to the crest of the greater tubercle of the humerus (Neumann, 2017).

Motion Capture

Kinematics is the measure of movement, or can be described as the description of motion through displacements, velocities, and accelerations. Kinematic motion can be measured in two or three dimensions, but for reasonable accuracy, a calibrated three-dimensional (3D) system is necessary (Whittle, 2007). Kinematic systems use a 3D calibration device that can be viewed by infrared cameras displayed around the testing room. The computer software program can calculate the relationship between the 3D position of markers and the 2D position of those markers in view of the cameras. Passive reflective markers are placed directly on clean skin over bony landmarks to identify the position and orientation of the limb segment to calculate the joint center. When a subject is in front of the cameras, the calibration is reversed where the 3D positions are calculated for the markers placed upon the subject's limbs. Data is then collected as frames, or a series of time intervals. If the marker is only seen by one camera, the 3D location cannot be calculated. To compensate, computer software can estimate the location by using data from earlier or later frames. Measurement accuracy largely depends on the field of view of the cameras. Accuracy describes the relationship between where the markers are and where the system thinks they are. Most systems are accurate measuring joint angles and positions of limbs. Kinematic systems also require a differentiation for acceleration due to the noise that leads to unusable data. A low-pass filter can compensate, but generally are poor at measuring acceleration.

Motion capture is a unique way of measuring joint angles in a specific space over time. For this study, it is essential to use motion capture to quantify the angle of the TH joint during three ADL tasks. Motion capture provides a uniform and accurate way of calculating angles during movement as compared to therapists measuring joint angles with goniometers after every limb movement during a task. This study focuses on the kinematic assessment of three ADL tasks: 1) combing the hair, 2) reaching across the body and 3) reaching to the back pocket. These tasks were chosen to simulate UE functional demands and workspace of the shoulder. The combing task corresponds to grooming ability, cross body simulates upper extremity dressing, and reach to back pocket simulates toilet hygiene. The ASES and goniometric measurements may not be sufficient to determine compensation strategies in patients with rotator cuff tears, while motion capture can (Vidt et al., 2016). Motion capture is a reliable and valid tool that can accurately calculate the TH joint angles during performance of ADL tasks for this study.

Rotator Cuff Pathology

Subacromial impingement syndrome (SIS) is widely accepted as an etiological factor in the development of a rotator cuff tear (Freygant et al., 2014; Neer, 1972; Teefey et al., 2000). SIS is defined as the reduction of acromiohumeral distance (AHD), resulting in compression of the supraspinatus tendon beneath the acromion process and superior aspect of the humeral head (Neer, 1972; Saupe et al., 2006). A reduction in AHD from scapular plane abduction and flexion is the main culprit to RC degeneration, subacromial bursitis, and pain (Flatow et al., 1994; Ludewig & Cook, 2000; Saupe et al., 2006). The AHD has been reported to be the lowest when the arm is abducted to 90 degrees (Giphart, van der Meijden, & Millett, 2012). With continuous irritation, a RC tear is most likely to occur. The supraspinatus is the most commonly torn RC muscle due to impingement (Opsha et al., 2008). It was originally believed tears occur anteriorly and progress posteriorly, but a recent study has found a common location in small, full-thickness tears that occur more posteriorly (83%), or about 15 mm posterior to the biceps tendon (H. M. Kim et al., 2010).

There are many ways to classify RC tears. The Physician Assistants responsible for consenting each subject used the Cofield Classification of Rotator Cuff Tears (Cofield, 1982) identified as follows: small <1cm; medium=1-3cm; large= 3-5cm; massive>5cm. To classify tear shape, they used the Full-thickness rotator cuff tear: Ellman and Gartsman Classification (Ellman & Gartsman, 1993) identified as; crescent, Reverse L, L-shaped, Trapezoidal, and Massive Tear.

A RC tear usually results in pain, weakness, and stiffness within the GH joint. People suffering from RC tears may be limited in completing their everyday activities because of pain. Pain is the most limiting factor that hinders performance. Most people with a supraspinatus tear feel pain in the anterior shoulder which radiates down the arm. Usually, people have pain when performing overhead lifting or reaching activities. Nakajima et al. (2012) found both asymptomatic and symptomatic shoulders in 462 individuals had experienced muscle weakness with shoulder elevation leading to restricted ADL performance. While performing shoulder abduction, the supraspinatus is responsible for keeping the humeral head in contact with the glenoid fossa. Unfortunately, an altered contact position of the humeral head and the glenoid fossa are attributing to abnormal kinematics due to displaced ligaments from RC repair (Bey et al., 2011; Wu et al., 2012; Yamaguchi et al., 2006). Compensatory movements can lead to serious secondary conditions such as overuse of the muscles around the joint, increased risk of soft tissue problems, and degenerative joint disease (de Groot, Angulo, Meskers, van der Heijden-Maessen, & Arendzen, 2011; Veeger, Magermans, Nagels, Chadwick, & Van Der Helm, 2006). With a RC tear, the humeral head is not supported correctly during movement, which may lead to development of internal shear forces causing a tear to occur. When the supraspinatus is injured, the force couple among the cuff is disrupted. This imbalance may cause the accessory muscles to be activated to complete a desired motion. Of these accessory muscles, the middle deltoid is usually recruited first to complete shoulder abduction. As dysfunction continues, other accessory muscles, such as the pectoralis major and upper trapezius, are recruited. When the prime mover is no longer performing the action and other accessory muscles are being recruited to perform the action, this phenomenon is defined as compensation.

Conservative treatment is the initial form of treatment when treating RC tears. After consultation from the physician, patients are sent to an outpatient rehabilitation clinic with the goal of alleviating symptoms and restoring ROM (Matava, Purcell, & Rudzki, 2005). If no improvement follows, then they are referred back to their physician for surgical repair. The delay of surgery is common, even though there is supported evidence to suggest success of a RC repair and duration of symptoms are correlated (Bassett & Cofield, 1983; Feng, Guo, Nobuhara, Hashimoto, & Mimori, 2003; Habernek, Schmid, & Frauenschuh, 1999). RC repair is a common surgical procedure that repairs the torn tendon and re-attaches it to the bone. There are many different ways to perform RC repair such as arthroscopic, open, and mini-open repair. The physician for this study performed the majority of surgeries arthroscopically, with some using a mini-open technique. To date, there is mixed evidence to support one surgical technique over another for treating full-thickness tears.

Occupational Performance

As defined by AOTA’s Practice Framework (2014), occupational performance is the act of doing and accomplishing a selected action, activity, or occupation, which results from the dynamic transaction of the client, context, and activity. Improving skills and patterns in occupational performance leads to engagement in occupations or activities ("Occupational

Therapy Practice framework: domain and process," 2014). One can quantify their success from rotator cuff repair by their perception of their occupational performance. Patient may be able to complete an activity, but may use improper technique or painful strategies to complete essential tasks. Improper UE limb function to complete a task could lead to further long term dysfunction impacting the structure and integrity of the joint. This would ultimately damage the joint resulting in pain, further surgery, and decreased occupational performance due to inability to functionally use the shoulder.

Upper limb dysfunction impedes one's daily physical function (Walker-Bone et al., 2004), such as activities of daily living (ADL). According to the Occupational Therapy Practice Framework (2014), ADLs are the activities in which you take care of your own body (Rogers & Holm, 1994) and are fundamental in survival and well-being (Christiansen, Hammecker, Bonder, & Wagner, 2001). Shoulder function is essential for optimal occupational performance, such as maintaining balance, transfers, performing ADLs and effective hand function (Rizk, Christopher, Pinals, Salazar, & Higgins, 1984). Injury to the upper limb, such as rotator cuff tears, can result in decreased ability to perform daily activities. According to WHO's International Classification of Functioning, Disability, and Health (ICF) model (Organization, 2001)a rotator cuff tear would be classified into four of six domains including "activity", "participation", "body functions and structure", "health condition", to describe health and health-related states. Recently, Vora et al. (2018) found patients were more concerned with difficulty in performing daily tasks due to decreased arm function of rotator cuff compared to pain. They found 20% were still unable to use the limb after surgery, 16% had severe, unbearable pain, and 88% were satisfied at 1-year follow up. This alludes to patients' needs for better treatment from investigating kinematics of the UE to allow engagement in ADLs. Evaluating pain and ability to perform self-care activities are relevant to indicate patient success through the repair process. The American Shoulder and

Elbow Surgeons (ASES) shoulder assessment was chosen for this study because it evaluates pain and ADL function. The comparison of scores before and after surgery will measure perceived shoulder performance of ADLs. The ASES has been shown to have strong correlation to other self-reported outcome scores, excellent reliability (ICC=0.84-0.96, SEM=6.7) and excellent responsiveness (0.9-3.5) (Kocher et al., 2005; Michener, McClure, & Sennett, 2002; Roy, MacDermid, & Woodhouse, 2009). The ASES is composed of 11 items: the Visual Analog Scale (VAS) and 10 functional ADLs. It is scored with 50% weight for pain and 50% weight for function with scores ranging from 0-100 and a higher score indicating better perceived shoulder function. The kinematic analysis will evaluate how well the subjects will perform the task, while the ASES will measure how well the subjects perceive they can perform the ADL task before and after surgery dependent on their injured arm status. The patient is able to return to their desired habits, roles, and rituals when engagement in occupation is possible. One's inability to perform their everyday tasks could decrease their occupational performance and quality of life (QOL).

Rotator Cuff Repair Success

After surgery, literature indicates many factors influence the success of a rotator cuff repair. A current study by Abtahi, Granger, and Tashjian (2015) states failure rates after arthroscopic repair of large or massive tears have been reported to range from 34%-94%. Abtahi et al. (2015) found surgical procedure, age, size of tear, muscle integrity, and rehabilitation protocols to be contributing patient factors affecting RC repair success. Rotator cuff (RC) tears are a common musculoskeletal injury with prevalence increasing from 12.8% to 50.0% from fifty to eighty years old, respectively (Yamamoto et al., 2010). The United States Census Bureau predicts by 2030, more than 20 percent of the U.S. residents (about 72 million people) will be aged 65 and over, compared with 13 percent in 2010 (Ortman, Velkoff, & Hogan, 2014). With a rise in the geriatric population, RC tears could become even more prevalent due to the high correlation with age. Many researchers indicate size of the tear may play a critical role in recovery; varying rates range from 6% to 91% in large and small tears, respectfully (Boileau et al., 2005; Frank et al., 2008; Galatz, Ball, Teefey, Middleton, & Yamaguchi, 2004; Lafosse, Brozska, Toussaint, & Gobezie, 2007). Smaller, full-thickness tears have approximately 5% re-tear rate, medium tears are 20%, large tears are 27%, and massive tears range from 50-90% (Kluger, Bock, Mittlböck, Krampla, & Engel, 2011; Motamedi, Urrea, Hancock, Hawkins, & Ho, 2002).

Although rehabilitation protocols can differ across the physicians' approaches, most follow basic milestones of implementing passive range of motion (PROM) at 4 to 6 weeks and active range of motion (AROM) with strengthening at 12 weeks post-surgery. It is important for occupational therapists and other practitioners to consider the intensity of the rehabilitation program and when to implement passive range of motion in individuals who have undergone surgery. Some studies have not found statistically significant differences among healing rates and functional outcomes in those who undergo early PROM or delayed ROM of 6 weeks (Keener, Galatz, Stobbs-Cucchi, Patton, & Yamaguchi, 2014). Lee, Cho, and Rhee (2012) found, when comparing two rehabilitation protocols, the aggressive passive ROM group had a greater amount of re-tear (23.3%) compared to the limited early passive ROM group (8.8%), but the difference was not statistically significant. They suggest a gentle rehabilitation protocol that eases patients into limited passive ROM is better for tendon healing and decreases potential risk of re-tear. An overarching, standard rehabilitation protocol is still controversial due to each patient's individual needs, symptoms, and tear size/type. Furthermore, people being treated with RC tears have an increased chance of developing another tear on the contralateral side when performing ADLs (Liem et al., 2014). This may be due to the increased amount of stress placed on the uninjured shoulder complex while performing tasks.

Literature Review

To date, there is no published work that has investigated pre-and-post-operative TH joint kinematics of ADLs in adults with a rotator cuff tear. Currently, our team is the only group in the world investigating UE kinematics before and after rotator cuff repair surgery using motion capture. Studies have primarily focused on evaluating upper limb function using young, healthy individuals. Magermans, Chadwick, Veeger, and van der Helm (2005), investigated the requirements of upper extremity motions during ADLs on 24 healthy female subjects. They argued self-reported outcomes are commonly used to evaluate surgical outcomes, but a more quantitative approach should be used to quantify kinematics. Knowing how ADLs are performed is valuable information for evaluation and diagnosis by clinicians. The authors found large axial rotations were needed to perform two ADL tasks: perineal care task and hair combing task. This study provides insight as to which joint angles are required to perform ADL tasks and large demands are placed on the shoulder when performing ADLs. Although it is helpful to understand the mechanics of healthy shoulders and RC tears as a baseline, unhealthy populations should be evaluated in comparison to healthy shoulders to measure the rehabilitation process on returning to prior level of function.

Although full ROM after surgery is the ultimate goal, some may only regain functional ROM after rotator cuff repair surgery. Functional ROM is the needed range the arm requires to perform a task. Namdari et al. (2012) inspected the functional shoulder range of motion for ADLs using 40 shoulders comprised of 20 healthy volunteers. Subjects performed each functional task of the American Shoulder and Elbow Surgeons assessment (ASES), Simple Shoulder Test (SST) and University of Pennsylvania Shoulder Score (PSS). Their results including functional ROM of flexion (121°± 6.7°), extension (46°± 5.3°), abduction (128°± 7.9°), cross-body adduction (116°± 9.1°), external rotation (59°± 10°), and internal rotation 102°± 7.7°) were all below the full range of motion to complete these ADL tasks.

Several studies have investigated shoulder specific movements required for ADLs. Many have used a variety of measurement tools such as standard goniometry and 3D motion analysis systems with challenges measuring functional motion due to the complexity of the shoulder joint. Khadilkar et al. (2014) has shown full shoulder ROM is not necessary to perform ADLs. In this study, including 10 healthy subjects without any shoulder complaints, they used video cameras and Dartfish software to capture shoulder movements during five ADLs from the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire. They quantified maximum, functional thoracohumeral joint angles and found sagittal plane flexion of 118° ±16°, abduction of 112° ±14° and 67°± 9° of extension. This indicates the shoulder does not need full ROM to perform ADL tasks. To provide useful information to clinicians, evaluating percentage of functional ROM achieved may be a useful indicator of operative success.

Extensive research has been done over the years investigating the rotator cuff, with more current research using motion capture to quantify joint kinematics of the upper extremely. Research conducted at University of North Carolina, by Vidt et al. (2016) and colleagues investigated the effects of rotator cuff tear on ADLs in older adults through kinematic analysis. This study used 18 older individuals (mean age 63.3 ± 2.2); 9 subjects had a supraspinatus RC tear and 9 were age and sex matched controls. The goal of their study was to evaluate the mechanics of the rotator cuff during seven ADLs post-operatively. Their findings include greater internal rotation to complete functional tasks (functional reach, functional pull, hair comb, and upward reach of 105°) within the RC tear group compared to a control (Vidt et al., 2016). They discuss the possibility of high amounts of internal rotation as an adaptive strategy to avoid pain.

Participants may be activating the deltoid and pectoral muscle to compensate in absence of a fully functioning supraspinatus rotator cuff muscle. Quantifying kinematics during the combing task from my study may highlight compensation strategies pre-and-post-operatively, providing a detailed look at compensation strategies.

Recently, Fritz et al. (2017) has demonstrated motion capture is effective for quantifying 3D upper extremity movement by evaluating return to work capacity using seated desk task ADLs. Twenty subjects were used in their study; 10 subjects were 9-12 weeks post-operative from supraspinatus repair surgery with 10 healthy matched controls. They measured thoracic and thoracohumeral joint kinematics, temporal-spatial parameters, and electromyography (EMG) muscle activity by using an upper extremity model during 10 ADLs and 3 rehabilitation exercise tasks. They found significant differences between groups in thoracohumeral joint motion during the hair comb maximum flexion angle (p =.004), reach abduction/adduction ROM (p =.001), reach flexion/extension ROM (p =.020), and reach extension minimal angle (p =.025). They concluded reduced supraspinatus was expected; it was only significantly reduced during reach to back pocket task with significantly less abduction ROM. They discovered minimal significant differences between the repair group and healthy shoulder group kinematics for thoracic and thoracohumeral joints supporting restoration of functional ROM at 9-12 weeks after repair surgery. In contrast, one hypothesis in the current study compares the repaired shoulder before and after surgery to see if significant differences in ROM arise between these groups at the thoracohumeral joint.

According to this author's most recent abstract submission (Appendix I) and poster presentation at OT Summit of Scholars, M. E. French, Schnorenberg, A. J., Magruder, B. N., Washburn,D. H., Mickschl, D. J., Grindel, S. I., and Slavens, B. A (2018) presented on the pre-to-post-operative GH joint kinematics of six subjects during the hair combing task in three movement planes (coronal, transverse, and sagittal). A statistically significant decrease in external rotation ROM (transverse plane) occurred from pre-operative (72.9± 26.9) to post-operatively (46.3 ±16.0) at the 3 month follow up. They concluded investigating one specific joint is not sufficient in understanding the UE kinematics during ADLs. Broadening the overall kinematics or combining all shoulder joints in analysis may be necessary to make definitive conclusions. Therefore, the current study is based on broadening the scope of kinematics to the TH joint. No statistical significance was found between pre-to-post operative SST or UCLA scores. They found inconclusive findings using these functional outcomes measures. The decrease in ROM and low functional scores may indicate decreased function due to pain. These functional outcome measures did not record pain. Therefore, a different measure (ASES) was used in the current study to assess pain. These findings support the investigation of the current hypotheses in determining differences in pre-to-post operative ROM during ADL performance.

A second conference paper (Appendix J) was submitted and presented as a poster at the annual Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) international conference. M. E. French, Schnorenberg, A. J., Magruder, B. N., Riebe, J. M., Inawat, R.R., Washburn, D. H., Mickschl, D. J., Grindel, S. I., Slavens, B. A (2018) presented on pre-to-post-operative GH joint kinematics of six subjects during three ADL activities in three planes of motion (coronal, transverse, and sagittal). When investigating three ADL tasks, there were significant differences in the hair comb task and crossbody reach, but not reach to back pocket. Decreased external rotation ROM pre-operative (72.9± 26.9) to post-operatively (46.3 ±16.0) at the 3 month follow up may indicate increased subacromial space leading to reduce risk of shoulder impingement and RC tears. A decrease in maximum abduction angle in combination with an increase in maximum external rotation angle for the combing task may indicate patients are reallocating ROM amongst different planes to complete the task.

Further investigation of all planes of all joints of the shoulder is warranted to understand compensation strategies. These conclusions support the reason for investigating specific planes of motion for specific tasks to investigate pre-to-post-operative ROM.

To provide the most clinically meaningful data, the thoracohumeral angle is the best practice to report shoulder angles of movement. Clinically, a similar ROM concept is used for ROM measurement using a standard goniometer (Latella & Meriano, 2003). Occupational therapists are trained to measure UE TH ROM using a goniometer. Thus this study focuses on the TH (humerus relative to thorax) joint instead of investigating other shoulder joints (i.e. AC, ST, SC, or GH). It is important for therapists to understand the data to use the information in their decision making for each patient's plan of care. Stated previously, motion capture provides a more accurate measurement of UE kinematics compared to standard goniometry. This study is intended to explain the unknown of whether the TH joint ROM is different before and after surgery and patients' perceived shoulder function 0-12 weeks before and 9-12 weeks after surgery. The author chose to investigate the TH joint, specific planes of motion specific to each task, and ADL tasks based off previous work (Fritz et al., 2017) and of the author's previous conference papers (M. E. French, Schnorenberg, A. J., Magruder, B. N., Riebe, J. M., Inawat, R.R., Washburn, D. H., Mickschl, D. J., Grindel, S. I., Slavens, B. A, 2018; M. E. French, Schnorenberg, A. J., Magruder, B. N., Washburn,D. H., Mickschl, D. J., Grindel, S. I., and Slavens, B. A, 2018).

The evidence suggests there is substantial amount of literature on rotator cuff repair and surgical success is a complicated construct to measure. Most studies have investigated young and healthy, or older populations after rotator cuff repair surgery performing ROM, work, or ADL tasks. Due to the prevalence of rotator cuff tears, more information is needed on the pre-operative and post-operative rehabilitation process due to peoples' shoulders not optimally functioning after repair. This decrease in function leads to a decrease in the ability to participate in ADLs.

II. Kinematics

Special Note- A version of the following chapter will be submitted to the Journal of Electromyography and Kinematics.

Introduction

Approximately one quarter of U.S. adults will have a rotator cuff (RC) tear in their lifetime, and about 300,000 RC repair surgeries are performed annually (Crawford, 2014). The supraspinatus is the most commonly torn rotator cuff muscle requiring surgical repair (Opsha et al., 2008). RC tears can impede physical function, such as one's ability to perform activities of daily living (ADLs), and maintain functional independence (Lin et al., 2008; Walker-Bone et al., 2004). The American Occupational Therapy Association Practice Framework (2014) defines ADLs as the tasks of taking care of one's own body. The surgery is associated with improved function, and patient satisfaction with the goal of surgical repair is to decrease pain, increase range of motion (ROM), and allow return to the workforce (Day et al., 2012; Nho et al., 2009). Although patients may be able to perform ADLs independently before surgery, they may be using altered kinematics due to injury and pain. While studies have compared post-operative thoracohumeral (humerus relative to thorax) joint kinematics of various populations (Fritz et al., 2017; Vidt et al., 2016), there is no known research assessing upper extremity (UE) joint kinematics of ADLs pre- and post-operatively, which may provide insight on the rehabilitation process. The purpose of this study is to compare thoracohumeral (TH) joint kinematics of three ADLs and shoulder function before and after supraspinatus repair surgery. It is hypothesized that TH joint kinematics and functional shoulder outcomes will be significantly different following rotator cuff surgery.

Methods

2.1 Subjects. Eight (8) subjects, three female and five male, aged 18+ (63.6 ± 6.3 years) identified with a supraspinatus RC tear and an asymptomatic contralateral shoulder participated in this study (Table 1). Subjects who had previous shoulder surgery, systemic inflammatory arthritis, and shoulder pathology in both shoulders, or who were pregnant were not included in this study.

Table 1- Subject Demographics

Subject	Gender	Surgical Arm	Dominant Arm	Tear Classification	Tear Size (cm)	Age (years)	Pre-operative session to Surgery (days)	Surgery to Post-operative session (days)
1	F	R	R	Medium	1.25	59	34	78
2	M	L	R	Medium	1.5	75	2	85
3	F	L	R	Medium	1	55	19	71
4	M	R	R	Medium	1	66	4	79
5	F	R	R/L	Medium	2.5	66	9	76
6	M	R	R	Large	4	60	5	80
7	M	R	R	Medium	1.5	68	2	76
8	M	R	R	Medium	2	60	26	65
Average					1.8	63.6	12.6	76.3
± SD					1.0	6.3	12.2	6.0

Screening and consent was obtained through the Orthopedic Clinic at Froedtert Hospital (Appendix A). Informed written consent was obtained from each subject prior to data collection. The University of Wisconsin-Milwaukee's Institutional Review Board (IRB) approved this study.

2.2 Data Collection. All data was collected at the UWM Mobility Lab. Subjects completed two sessions at the Mobility Lab; one session 0-3 months before their scheduled RC repair surgery and one session 9-12 weeks post-surgery. Anthropometric measurements were obtained before the start of each testing session. Each participant completed a self-evaluation of the ASES shoulder test to measure pain and perceived shoulder functionality at the beginning of each session (Appendix D). Each subject performed five (5) trials of three (3) ADL tasks and were recorded on the data collection sheet (Appendix C): hair combing (Figure 4), crossbody (Figure 5), and reach to back pocket (Figure 6) for both arms. Subjects were fitted with twenty-seven (27) passive reflective surface markers on the upper extremities based on an established model (Schnorenberg et al., 2014)(Appendix B).

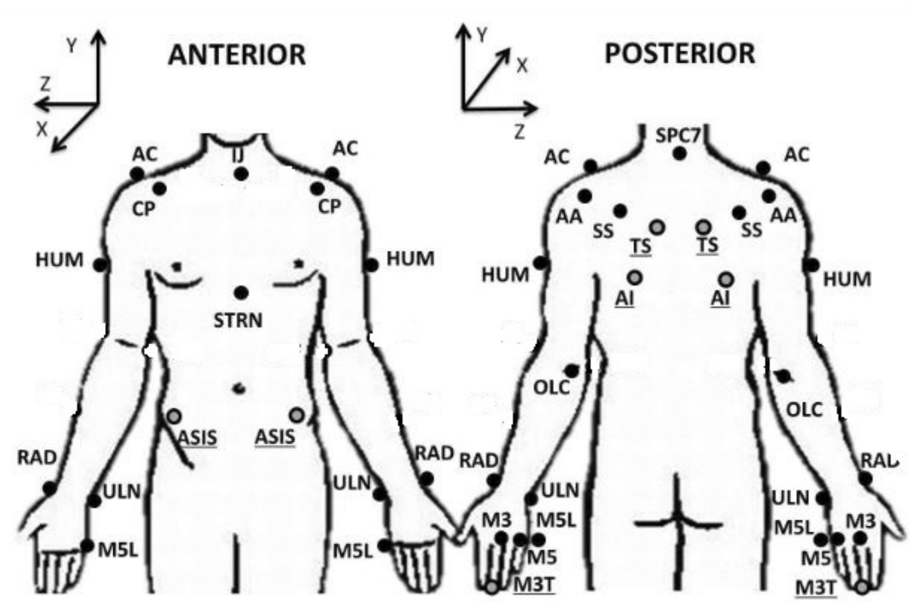

Figure 3. Custom 3D bilateral UE biomechanical model (Schnorenberg et al., 2014).

Kinematic data was collected at 120 Hz using a 15-camera Vicon T-Series motion analysis system (Oxford Metric Group, Oxford, UK). Due to subject's abilities, they were allowed to take breaks throughout data collection. The order of trials were consistent between all subjects completing reach to back pocket, comb, and cross body in that order.

Combing Task. With their arm resting at their side, subjects were instructed to comb their hair with a plastic comb (not actually letting the comb touch their hair) and then return their arm back to their side.

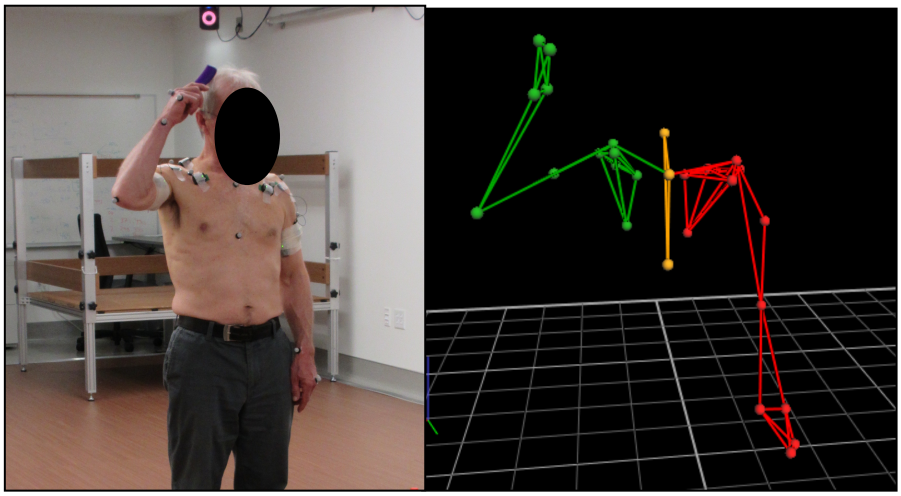

Figure 4. Subject performing hair combing task (left) and Vicon Nexus rendering of model (right).

Crossbody Task. With their arm resting at their side, subjects were instructed to reach across their body to touch their opposite arm (mid-humerus) and then return their arm back to their side.

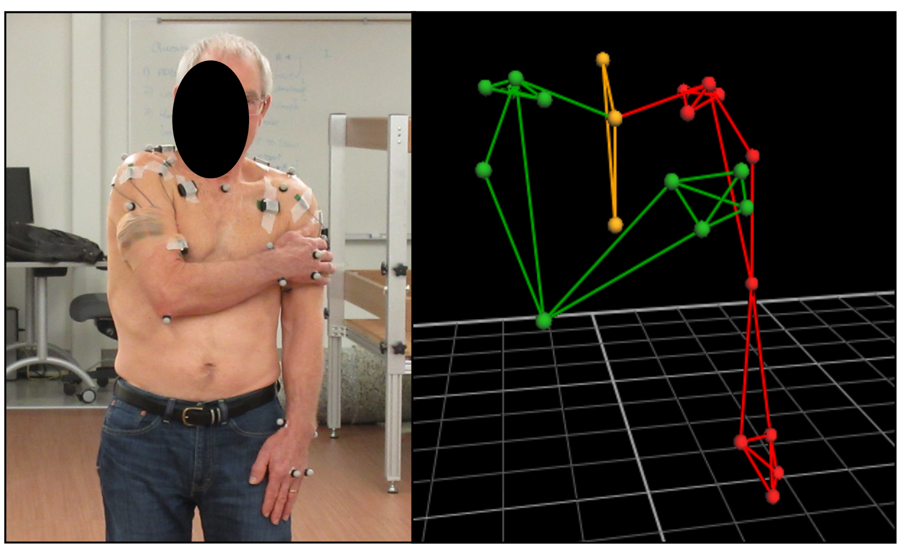

Figure 5: Subject performing crossbody task (left) and Vicon Nexus rendering of model (right).

Reach to Back Pocket Task. With their arm resting at their side, the subject was instructed to move their arm to touch their back pocket, and then bring it back to their side.

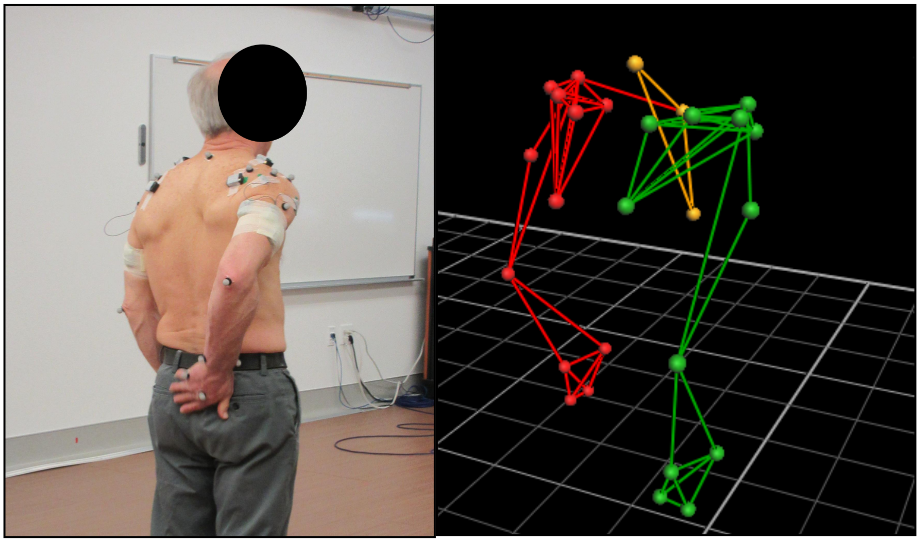

Figure 6: Subject performing reach to back pocket task (left) and Vicon Nexus rendering of model (right).

2.3 Data Analysis. Data was processed using Vicon Nexus 2.6.1 software (Figure 4, right) to label marker trajectories. Each marker for each trial for each subject was labeled correctly using the anatomical marker set (Figure 3; Appendix B). When the cameras are unable to see a marker, a gap is created. To fill gaps in trajectories, the software uses a mathematical equation to predict where the marker will be during the trial. All gaps were filled using the most appropriate mathematical equation for individual trials. The data was then filtered using a Woltring filter, similar to our lab's previous methods (Fritz et al., 2017; Schnorenberg et al., 2014). A custom UE biomechanical model was used to calculate the three-dimensional (3-D) UE joint kinematics (Schnorenberg et al., 2014). ROM was computed by subtracting the minimum angle from the maximum angle. The TH joint (humerus relative to the thorax) ROM was calculated in the abduction/adduction plane for combing task, the internal/external rotation plane for crossbody task, and flexion/extension plane for reach to back pocket task pre-and-post-operatively. ROM was calculated in the abduction/adduction plane for combing task pre-operatively in the surgical and non-surgical shoulders. The pre-and-post-operative ASES scores were calculated using an online tool provided by the orthopaedic surgeon. The group means and standard deviations were computed for each task. For Aim 1, comparisons were made between pre-operative and post-operative group average ROM. For Aim 2, comparisons were made between the surgical and non-surgical group average ROM. For Aim 3, comparisons were made between pre-operative and post-operative group average ASES scores.

***2.4 Statistical Analyses*.** This study had three aims and used two statistical methods to test five hypotheses. A Bonferroni correction, an adjustment made to P values when several dependent statistical tests are being performed, was completed for this study (p=0.01). For Aims 1 and 2, the Generalized Estimated Equation (GEE) was most appropriate to use due to the repeated measures design along with multiple trials completed by each subject (Twisk, 2013). This study is a repeated measures design because it investigates the same subjects completing two sessions at different points in time (i.e. pre-operative and post-operative sessions). Within these sessions, each subject performed multiple trials of the same task, also known as clustering. The GEE is a type of regression model used to account for clustering during statistical analysis. Since the data from multiple trials is dependent upon each other, the GEE provides the most accurate measure of the standard error. It does not skew the sample size to 24 (8 subjects multiplied by 3 trials each), but instead keeps the true sample size of 8. This method helps reduce the chance for false positives. For Aim 3, a paired t-test was used to compare pre-operative mean scores to post-operative mean scores (significance level p=0.01). A paired t-test calculates the difference between paired observations (i.e. before and after) and then performs a t-test of the differences and is most appropriate for this aim. All statistical tests were conducted using Statistical Analysis Software (SAS) (SAS Institute, Inc., Cary, NC). Graphs and tables were created in MATLAB (Math Works, Natick, MA) and Microsoft Excel (Microsoft, Redmond, WA).

Results

3.1 Kinematics. There was no statistically significant difference between abduction ROM pre-operatively (41.94°) compared to post-operatively (42.99°)(Figure 7). Average peak curves seem to have shifted downward from peak 52 degrees to only reaching about peak 40 degrees post (Figure 8). Large standard deviations post may indicate higher variability in performing this task. There was a statistical difference of 14.52° in internal/external rotation ROM during the crossbody task pre-operatively (90.75°) to post-operatively (105.27°) (p= 0.0120). Slight reduction in extension post-operatively. No statistical significant change in flexion/extension ROM from pre-operatively (38.43°) to post-operatively (35.56°) during the reach to back pocket task. There was no statistically significant difference of the TH joint abduction/adduction ROM between the surgical (41.94°) and non-surgical (49.80°) shoulder pre-operatively. There was no statistically significant difference between the group average (Figure 9); however, the bar graph indicates great variability among the 8 subjects for abduction ROM pre-to-post-operatively. The next graph depicts the subjects split into three possible groups; Group A is supraspinatus tendon involvement only, Group B is supraspinatus and other tendons involved, and Total Group is all subjects. Although statistics were not applied between these groups, splitting the groups seems to have a wash out effect on the pre-to-post-operative ROM. Details of the comprehensive statistical results can be found in Appendix F.

Aim 1, Hypothesis A: The TH joint abduction/adduction ROM will be statistically different pre-operatively compared to post-operatively for the combing task.

Summary of Aim 1, Hypothesis A. There was no statistically significant difference between abduction ROM pre-operatively (41.94°) compared to post-operatively (42.99°) (Figure 7). Average peak curves seem to have shifted downward from peak 52 degrees to only reaching about peak 40 degrees post (Figure 8). Large standard deviations post may indicate higher variability in performing this task.

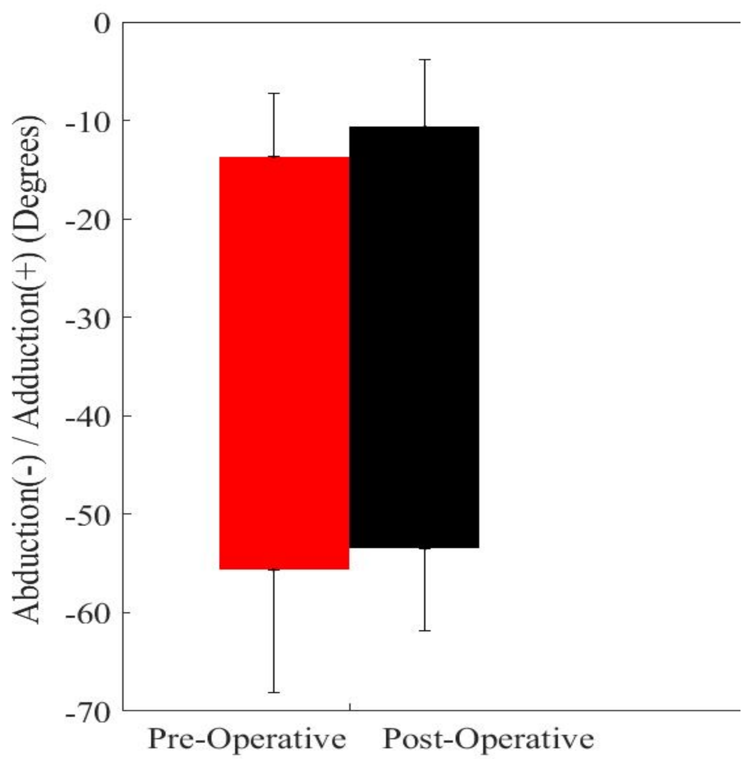

Figure 7. Group mean, ±1 standard deviation, peak TH joint angles; pre-operative (red) vs. post-operative (black). Statistical significance (p<0.01) indicated by (*) average ROM during the hair combing task.

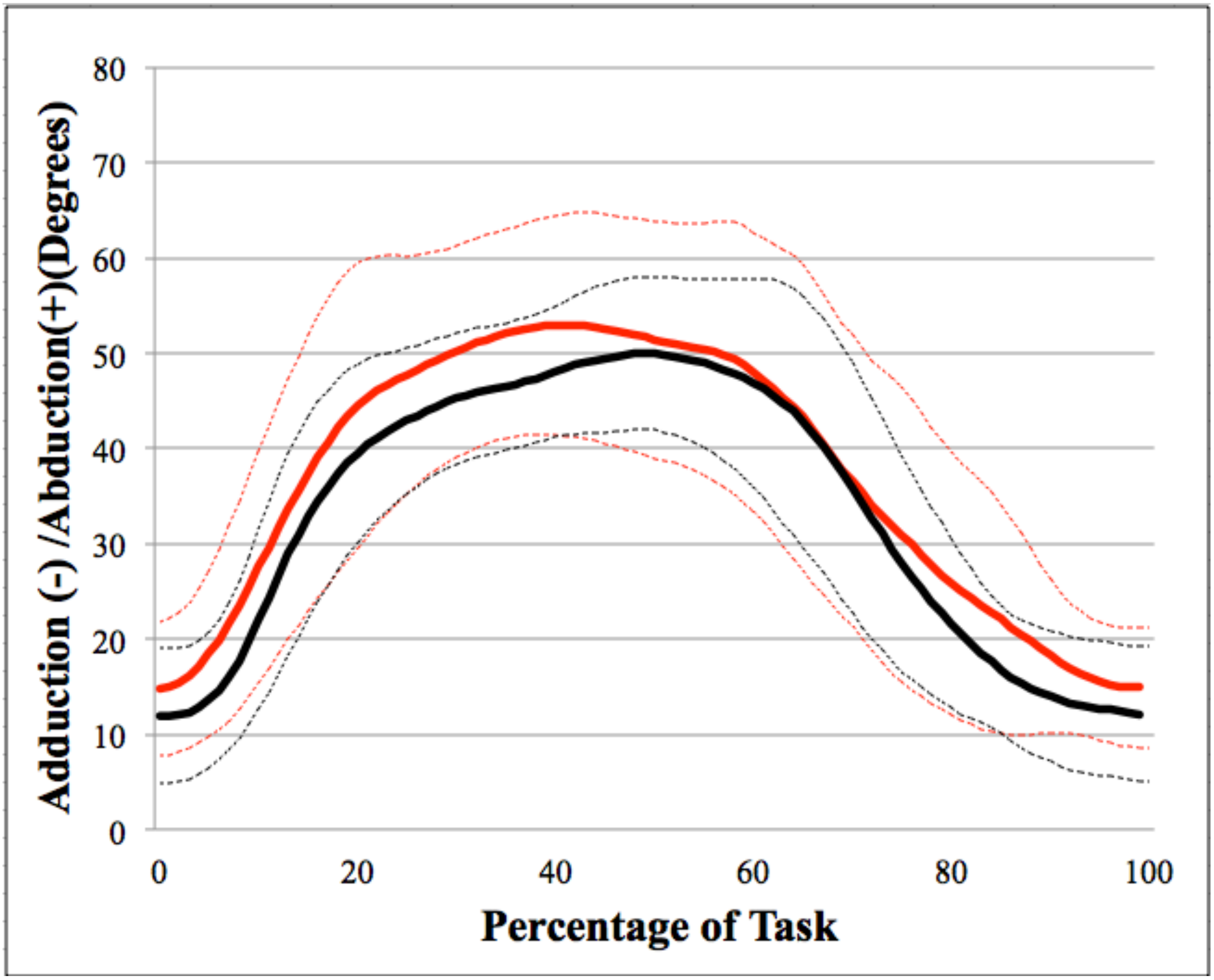

Figure 8. Group mean (solid) ±1 standard deviation (dashed) TH joint angles in the coronal plane; pre-operative (red) vs. post-operative (black).

Table 2- TH Joint Angle Peaks and ROM for Abduction/Adduction During Hair Comb Task

Trial #	Max TH Joint Angle (degrees)		Min TH Joint Angle (degrees)		ROM TH Joint (degrees)	
	Pre-Operative	Post-Operative	Pre-Operative	Post-Operative	Pre-Operative	Post-Operative
1	-10.46	-18.62	-52.68	-49.33	42.22	31.70
2	-12.35	-18.77	-45.76	-68.23	33.41	52.00
3	-10.55	-17.52	-48.50	-61.54	37.95	44.06
4	-10.73	-7.13	-42.11	-53.00	31.38	45.87
5	-11.90	-7.81	-46.78	-49.95	34.87	42.14
6	-13.30	-7.89	-47.62	-50.94	34.33	43.05
7	-19.46	-18.34	-59.63	-58.80	40.17	40.46
8	-18.62	-16.96	-69.17	-62.32	50.56	45.36
9	-20.28	-17.09	-63.88	-58.91	43.60	41.82
10	-26.07	-19.99	-56.71	-60.57	30.64	40.58
11	-26.08	-18.94	-55.44	-62.09	29.36	43.16
12	-9.47	-19.29	-72.34	-62.94	62.87	43.65
13	-5.49	-9.93	-54.38	-51.59	48.88	41.66
14	-8.78	-9.79	-75.30	-55.15	66.52	45.35
15	-22.35	-9.98	-69.72	-48.10	47.37	38.12
16	-20.02	-8.33	-70.28	-38.23	50.25	29.90
17	-20.46	-7.98	-69.03	-38.03	48.57	30.06
18	-10.47	-8.74	-58.41	-39.53	47.94	30.79
19	-10.13	-4.12	-60.37	-57.52	50.24	53.41
20	-10.25	-5.42	-58.48	-60.89	48.23	55.47
21	-5.35	-4.27	-31.68	-57.16	26.33	52.89
22	-7.11	2.12	-34.35	-43.60	27.24	45.72
23	-5.93	-0.96	-37.64	-48.83	31.71	47.88
24	-	0.17	-	-46.57	-	46.74
Average ± SD	-13.72 6.47	-10.65 6.85	-55.66 12.43	-53.49 8.40	41.94 10.90	42.99 7.12

Aim 1, Hypothesis B: The TH joint internal/external rotation ROM will be statistically different pre-operatively compared to post-operatively for the crossbody task.

Summary of Aim 1, Hypothesis B. There was no statistical difference of 14.52° in internal/external rotation ROM during the crossbody task pre-operatively (90.75°) to post-operatively (105.27°)(p= 0.0120)(Figure 9) with similar performance curve depicted (Figure 10).

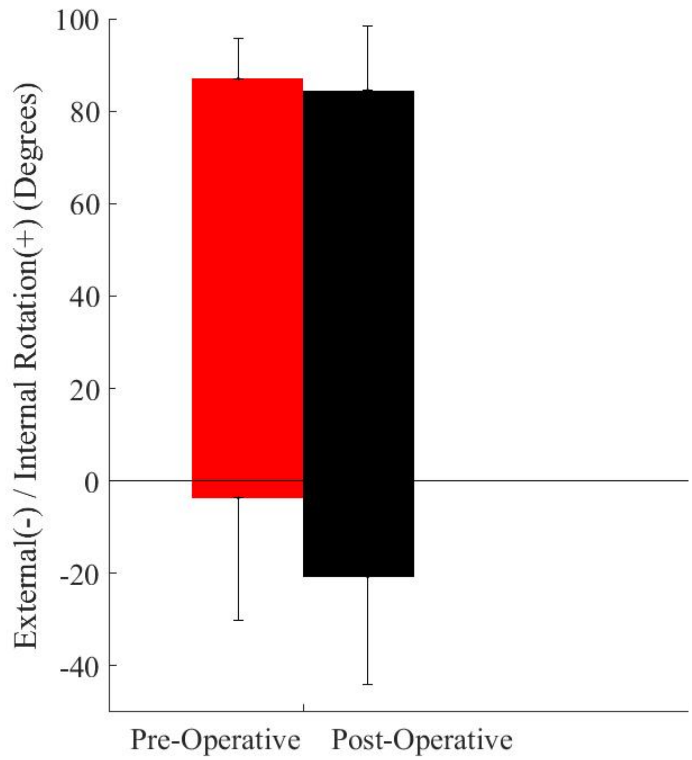

Figure 9. Group mean, ±1 standard deviation, peak TH joint angles; pre-operative (black) vs. post-operative (red). Statistical significance (p<0.01) indicated by (*)average ROM during the crossbody task.

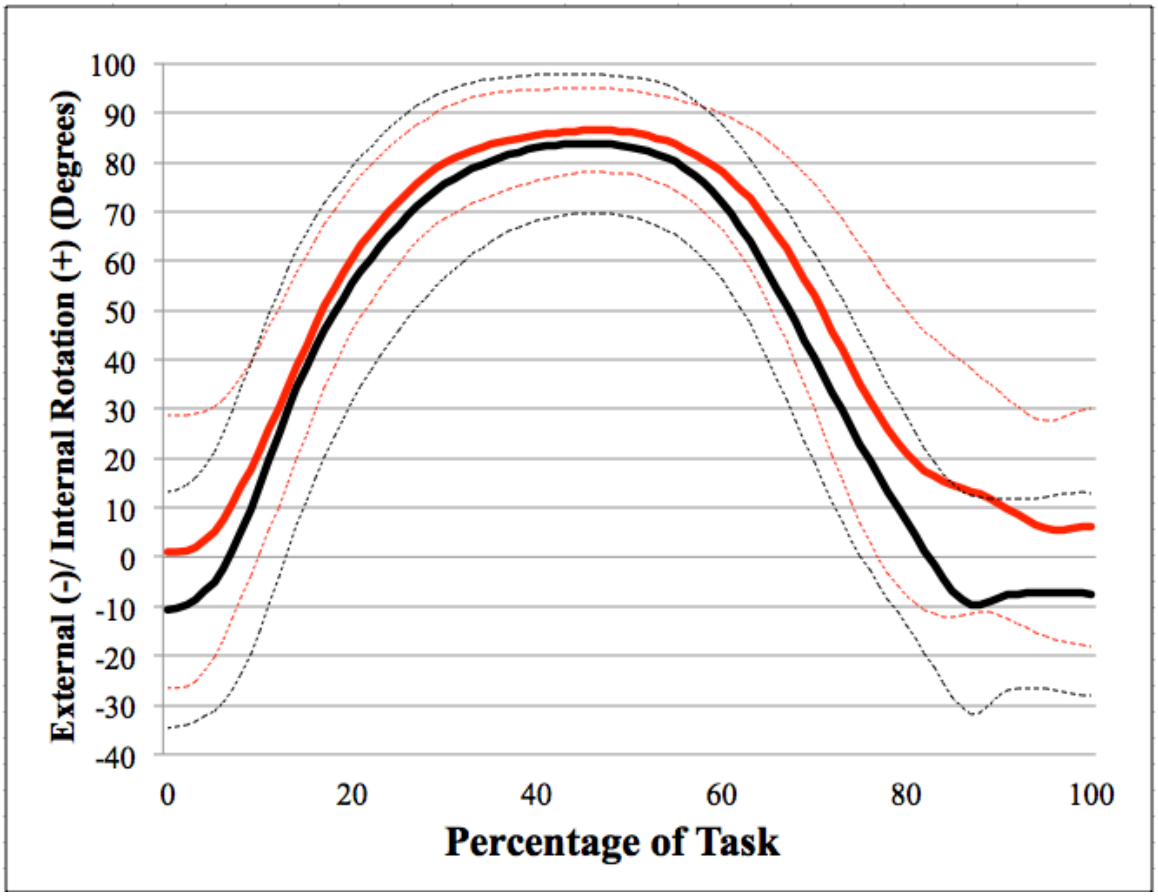

Figure 10. Group mean (solid) ±1 standard deviation (dashed) TH joint angles in the transverse plane; pre-operative (red) vs. post-operative (black).

Table 3- TH Joint Angle Peaks and ROM for Internal/External Rotation During Crossbody Task

Trial #	Max TH Joint Angle (degrees)		Min TH Joint Angle (degrees)		ROM TH Joint (degrees)	
	Pre-Operative	Post-Operative	Pre-Operative	Post-Operative	Pre-Operative	Post-Operative
1	87.39	105.97	37.47	16.08	49.92	89.89
2	91.60	108.69	37.12	16.91	54.49	91.78
3	95.44	110.30	36.25	20.77	59.19	89.53
4	98.91	88.51	16.48	10.71	82.43	77.80
5	96.24	94.40	17.42	-1.06	78.82	95.46
6	100.10	95.07	17.93	-1.38	82.17	96.45
7	96.09	84.96	-48.67	-43.97	144.76	128.93
8	95.53	85.06	-38.21	-56.52	133.74	141.58
9	93.31	88.76	-48.81	-52.04	142.12	140.80
10	93.21	92.29	8.12	-7.70	85.08	99.99
11	92.75	94.62	9.75	-20.35	83.01	114.97
12	91.10	95.16	-1.28	-11.63	92.38	106.79
13	72.32	84.28	-34.97	-34.73	107.29	119.01
14	76.14	90.05	-33.80	-34.54	109.94	124.59
15	73.45	82.21	-20.60	-25.75	94.04	107.95
16	81.72	64.08	-1.45	-9.40	83.17	73.47
17	80.27	65.93	-8.05	-10.78	88.32	76.71
18	78.17	62.55	-9.95	-13.37	88.12	75.93
19	79.01	68.14	15.93	-40.57	63.08	108.71
20	77.71	68.86	13.62	-37.52	64.09	106.38
21	77.10	69.72	13.13	-25.76	63.97	95.48
22	87.43	77.10	-20.64	-49.05	108.07	126.15
23	87.43	75.31	-23.00	-46.11	110.43	121.42
24	87.15	76.61	-22.13	-39.98	109.28	116.59
Average	87.06	84.53	-3.68	-20.74	90.75	105.27
± SD	8.58	13.90	26.42	23.32	26.14	19.84

Average maximum, minimum, and ROM TH joint angles in abduction/adduction reported in degrees. Trials 1-3 were completed by subject #1, trials 4-6 were completed by subject #2, etc.

Aim 1, Hypothesis C: The TH joint flexion/extension ROM will be different pre-operatively compared to post-operatively for the reach to back pocket task.

Summary of Aim 1, Hypothesis C. No statistical significant difference in flexion/extension ROM from pre-operatively (38.43°) to post-operatively (35.56°) during the reach to back pocket task (Figure 11) with similar peak values (Figure 12).

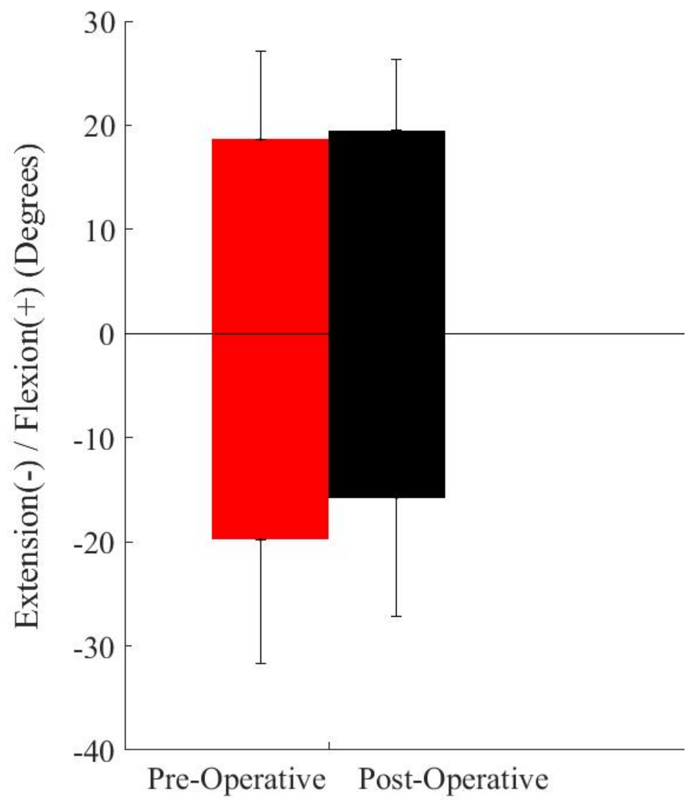

Figure 11. Group mean, ±1 standard deviation, TH joint ROM; pre-operative (red) vs. post-operative (black). Statistical significance ($p<0.01$) indicated by (*) average ROM during the reach to back pocket task.

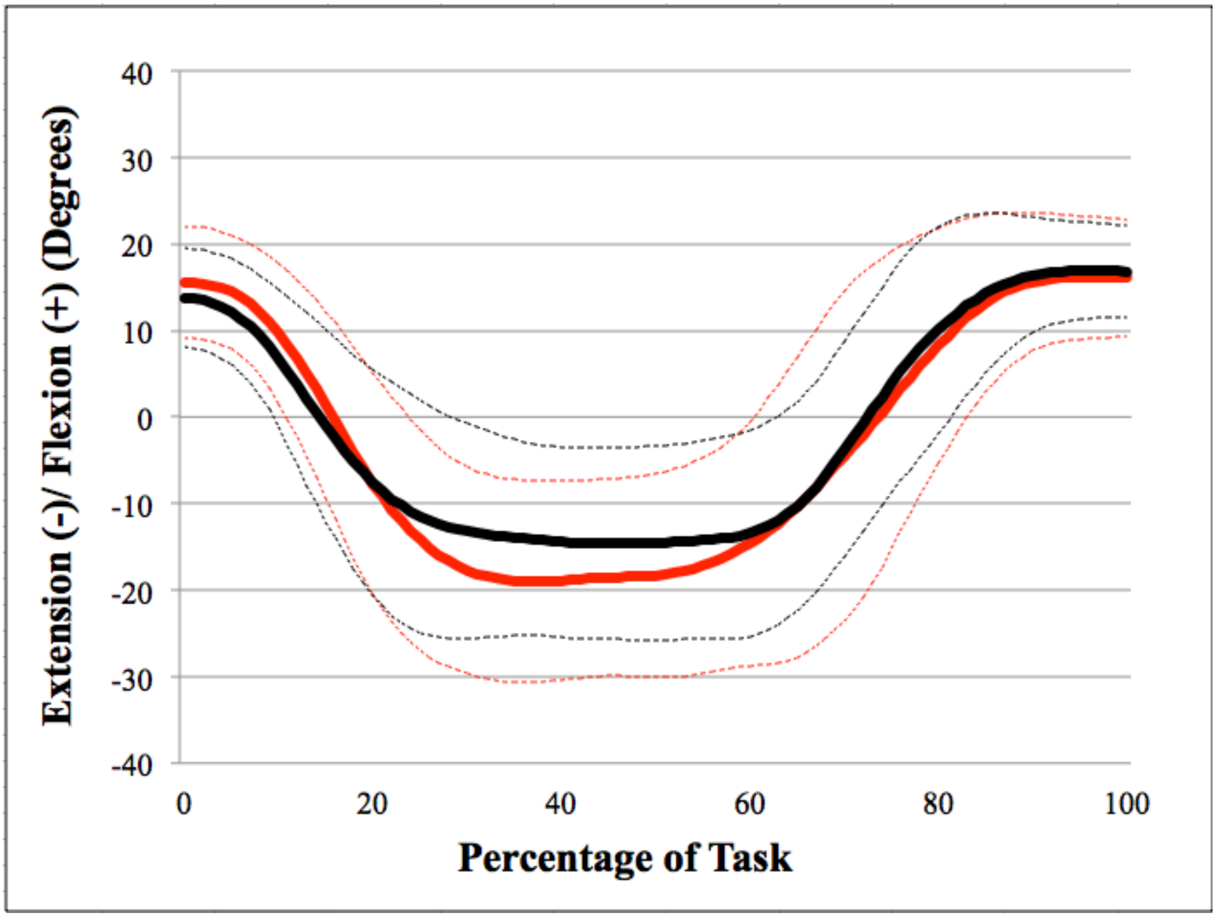

Figure 12. Group mean (solid) ±1 standard deviation (dashed) TH joint angles in the sagittal plane; pre-operative (red) vs. post-operative (black).

Table 4- TH Joint Angle Peaks and ROM for Flexion/Extension During Reach to Back Pocket Task

Trial #	Max TH Joint Angle (degrees)		Min TH Joint Angle (degrees)		ROM TH Joint (degrees)	
	Pre-Operative	Post-Operative	Pre-Operative	Post-Operative	Pre-Operative	Post-Operative
1	19.27	25.53	-29.97	-26.06	49.24	51.59
2	22.01	27.76	-28.87	-24.63	50.88	52.38
3	20.72	23.82	-31.01	-24.33	51.73	48.16
4	20.62	25.89	-13.34	-19.86	33.96	45.75
5	20.93	22.90	-16.60	-21.36	37.54	44.26
6	21.39	26.57	-16.95	-22.45	38.35	49.02
7	12.62	14.73	-23.40	-14.87	36.02	29.61
8	13.29	9.97	-22.65	-17.84	35.93	27.81
9	10.34	11.67	-22.15	-18.97	32.49	30.65
10	19.59	18.90	-17.74	-7.83	37.33	26.74
11	23.93	18.91	-18.94	-9.50	42.87	28.41
12	25.57	18.66	-15.15	-8.40	40.72	27.06
13	4.26	6.68	-45.54	-37.25	49.80	43.93
14	2.32	7.22	-47.86	-35.95	50.18	43.17
15	4.10	6.79	-35.67	-35.92	39.77	42.70
16	33.68	29.23	-9.95	-6.62	43.64	35.85
17	33.57	25.87	-10.32	-9.40	43.89	35.28
18	34.58	25.38	-10.65	-9.19	45.24	34.57
19	15.91	18.19	-14.90	-11.44	30.81	29.63
20	14.68	18.91	-15.69	-11.38	30.37	30.30
21	15.90	18.40	-17.72	-11.87	33.63	30.27
22	17.76	24.07	-0.82	3.22	18.59	20.85
23	20.22	21.15	-3.64	2.46	23.86	18.69
24	20.04	20.44	-5.58	0.98	25.63	19.46
Average ± SD	18.64 8.51	19.49 6.84	-19.80 11.92	-15.77 11.40	38.43 8.92	35.26 10.23

Average maximum, minimum, and ROM TH joint angles in abduction/adduction reported in degrees. Trials 1-3 were completed by subject #1, trials 4-6 were completed by subject #2, etc.

Aim 2, Hypothesis 1: The surgical TH joint abduction/adduction ROM will be different from the non-surgical shoulder in the combing task.

Summary of Aim 2, Hypothesis 1. There was no statistically significant difference of the TH joint abduction/adduction ROM between the surgical (41.94°) and non-surgical (49.80°) shoulder pre-operatively (Figure 13) with similar peak values (Figure 14). There was no statistically significant difference between the group average ROM (Figure 15). Group A's difference between pre-to-post operative ROM is about 17 degrees, Groups B's is about 8 degrees, and Total Group is about 11 degrees (Figure 16).

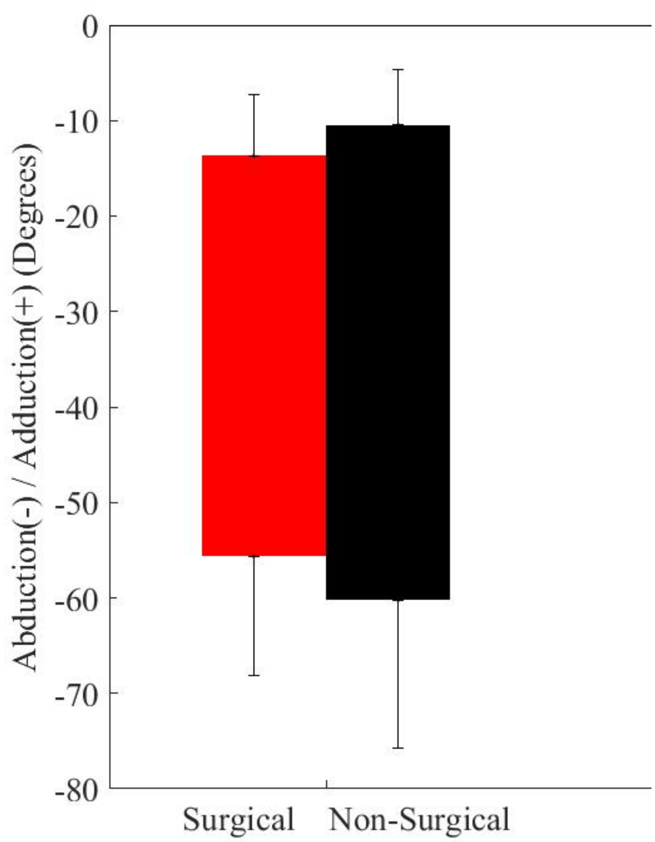

Figure 13. Group mean, ±1 standard deviation, peak TH joint angles; Pre-operative Surgical (red) vs. Non-Surgical (black). Statistical significance (p<0.01) indicated by (*) average ROM during the hair combing task.

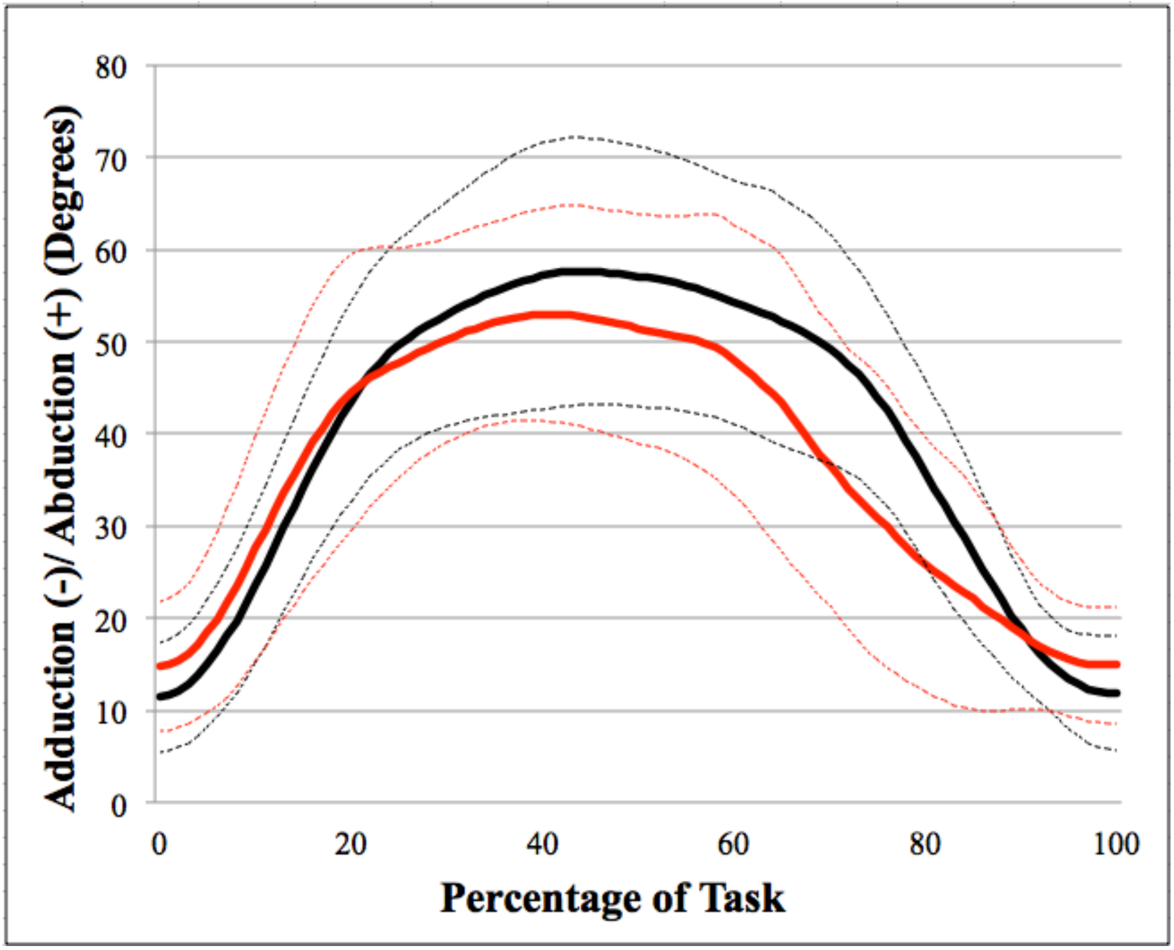

Figure 14. Group mean (solid) ±1 standard deviation (dashed) TH joint angles in the coronal plane pre-operatively; Surgical shoulder (red) vs. Non-surgical shoulder (black).

Table 5- TH Joint Angle Peaks and ROM for Abduction/Adduction During Hair Comb Task						
	Max TH Joint Angle (degrees)		Min TH Joint Angle (degrees)		ROM TH Joint (degrees)	
Trial #	Non-Surgical	Surgical	Non-Surgical	Surgical	Non-Surgical	Surgical
1	-6.10	-10.46	-78.70	-52.68	72.60	42.22
2	-5.36	-12.35	-73.51	-45.76	68.15	33.41
3	-5.94	-10.55	-76.44	-48.50	70.50	37.95
4	0.39	-10.73	-60.65	-42.11	61.04	31.38
5	-2.74	-11.90	-59.05	-46.78	56.30	34.87
6	-4.37	-13.30	-61.33	-47.62	56.96	34.33
7	-7.20	-19.46	-80.24	-59.63	73.04	40.17
8	-11.38	-18.62	-79.16	-69.17	67.78	50.56
9	-6.69	-20.28	-80.14	-63.88	73.46	43.60
10	-9.84	-26.07	-55.76	-56.71	45.91	30.64
11	-10.22	-26.08	-53.28	-55.44	43.06	29.36
12	-11.81	-9.47	-54.94	-72.34	43.13	62.87
13	-22.72	-5.49	-64.21	-54.38	41.49	48.88
14	-21.98	-8.78	-69.95	-75.30	47.97	66.52
15	-22.34	-22.35	-87.39	-69.72	65.06	47.37
16	-12.19	-20.02	-60.42	-70.28	48.24	50.25
17	-12.02	-20.46	-50.40	-69.03	38.38	48.57
18	-11.83	-10.47	-54.77	-58.41	42.94	47.94
19	-9.48	-10.13	-44.45	-60.37	34.98	50.24
20	-9.61	-10.25	-45.48	-58.48	35.87	48.23
21	-9.00	-5.35	-51.35	-31.68	42.35	26.33
22	-11.61	-7.11	-40.11	-34.35	28.51	27.24
23	-13.23	-5.93	-30.72	-37.64	17.49	31.71
24	-13.50	-	-33.51	-	20.00	-
Average	-10.45	-13.72	-60.25	-55.66	49.80	41.94
± SD	5.75	6.47	15.53	12.43	16.65	10.90
Average maximum, minimum, and ROM TH joint angles in abduction/adduction reported in degrees for Surgical vs. Non-surgical shoulders. Trials 1-3 were completed by subject #1, trials 4-6 were completed by subject #2, etc.						

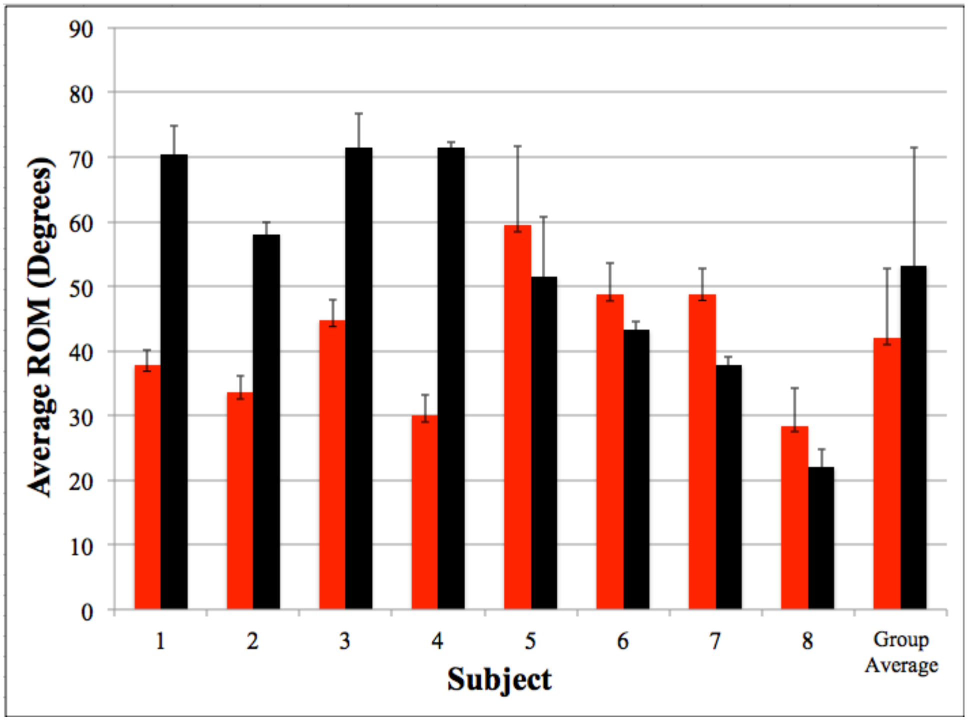

Figure 15. Surgical shoulder (red) vs. Non-surgical shoulder (black) average TH joint abduction/ adduction ROM for the pre-operative session.

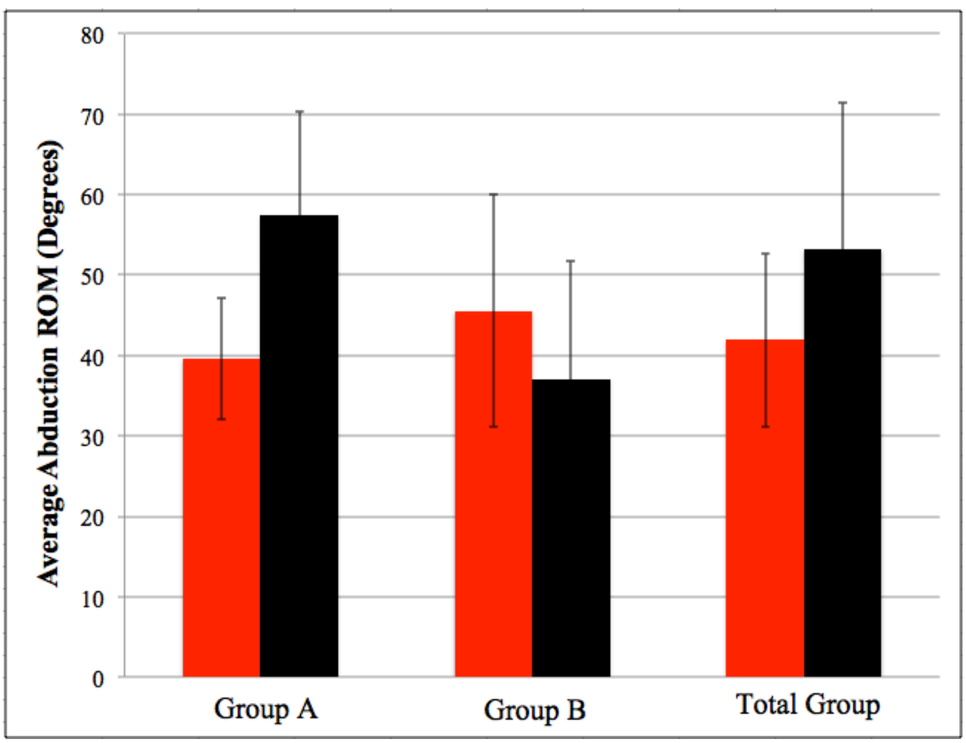

Figure 16. Surgical shoulder (red) and Non-Surgical shoulder (black) average abduction TH joint ROM for the pre-operative session for Groups A, B, and Total Group. Group A consists of subjects #1,2,3,4, and 6 with 1 single tendon tear (i.e supraspinatus) and Group B consists of subjects #5,7, and 8 with 1+ tendons (i.e supraspinatus, subscapularis, etc).

3.2 Shoulder Assessment Outcomes. The ASES scores showed no statistically significant difference when compared to pre-operative (black) to post-operatively (red); 5 subjects increased, 2 decreased, 1 had no change in scores. 6 subject's pain decreased, 2 subjects' pain increased. Overall, the group average indicates a decrease in pain (pre-operative: 4.5; post-operative: 2.8). Two subjects had no pain at 3 months follow up (Subjects 1 & 2).

Aim 3, Hypothesis 1: Subjects will have a significant difference in ASES scores between pre-and post-operative sessions.

Summary of Aim 3, Hypothesis 1. The ASES scores were not statistically different when compared to pre-operative (black) to post-operative (red)(Figure 17). Group average indicates minimal change in scores post-operatively. However, 2 subjects (Subjects 1 & 2) scored over 80% on the ASES post-opertively, indicating perceived better shoulder function. Individual answers for the ASES can be found in Appendix H. Six subject's pain decreased, while only 2 subjects' pain increased post-operatively. Overall, the group average indicates a decrease in pain (pre-operative 4.5, to post-operative 2.8) (Figure18). Two subjects had no pain at follow up.

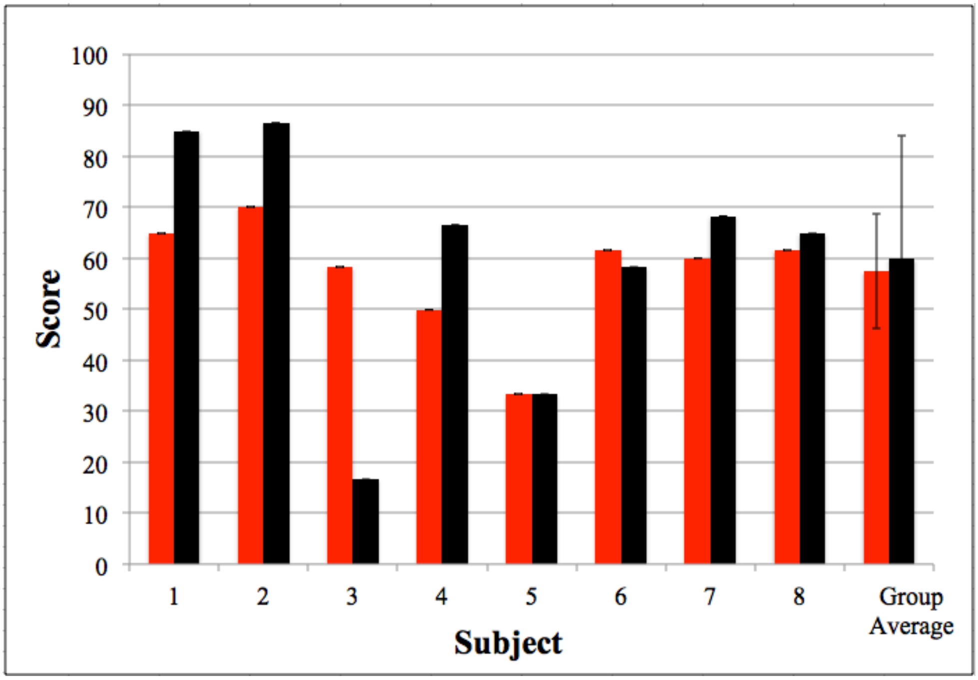

Figure 17. Pre-operative (red) vs. post-operative (black) scores of the ASES functional outcome measure.

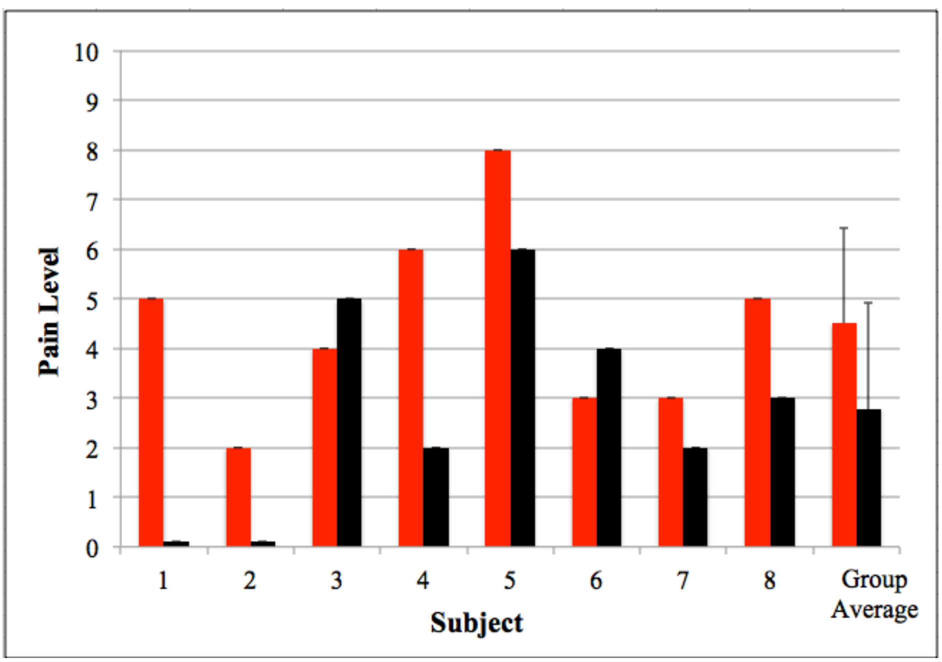

Figure 18. Pre-operative (red) vs. post-operative (black) scores of the Visual Analog Scale (VAS).

Discussion

This study provides a unique application of a validated UE model for kinematic analysis in combination with functional outcomes scores pre-and-post-opertively in people with rotator cuff tears. The supraspinatus muscle is primarily involved in thoracohumeral joint abduction with secondary actions as an external rotator when the arm is abducted and an internal rotator when the arm is flexed (Ackland & Pandy, 2011). Supraspinatus RC repair surgery allows return of ROM in abduction, a useful motion for many ADLs. This study focused on the thoracohumeral joint kinematics of the shoulder of specific planes of motion for ADLs before and after rotator cuff repair surgery, pre-operative TH joint kinematic analysis during abduction/adduction during the combing task, and pre-to-post analysis of ASES scores of the surgical shoulder. This is the first study that compared pre-operative to post-operative functional outcomes and kinematics of the TH joint during three ADL tasks.

Kinematics

Aim 1: Pre-operative to Post-operative Surgical shoulder ROM during 3 ADLs

There was no statistical significant difference between the pre-operative and post-operative TH joint abduction/adduction ROM during the hair-combing task. As the supraspinatus is the primary muscle for TH joint abduction, it was surprising to not see a difference between the abduction ROM during the combing task due to the supraspinatus being re-attached to bone during surgery in hopes of regaining more abduction. Finding no difference between abduction/adduction ROM at 3 months may indicate the supraspinstus has healed enough at this point in time to perform the ADL of combing similarly to before surgery. This indicates the supraspintus has the ability to perform its primary motion at 9-12 weeks similarly to before surgery. Although there was no difference from pre-to-post operatively in abduction ROM, Vidt et al. (2016) found a significant increase in internal rotation ROM during the combing task when comparing RC tear group to healthy controls in older adults. They suggest it may be a compensation strategy to avoid pain. Further investigation of other planes of motion compared to healthy controls is warranted to understand the kinematics of the TH joint during the hair-combing task because secondary motions may be possible due to repair surgery.

Looking at all trials of every subject, there was high variability between subjects when performing the ADL tasks. According to the graphs showing all trials for each task (Appendix G), large variability occurred. This was also found in another study which used Dartfish software to analyze of functional shoulder movements in healthy subjects. Khadilkar et al. (2014) found the group of healthy subjects had high variability in performance of the five ADLs tasks indicated by test-retest reliability using interclass correlation coefficients (ICC = 0.45 to 0.94). This suggests high inter-individual task variability, and inter-rater reliability (ICC = 0.68 to 1.00) showed moderate to excellent agreement.

A reason why there may not be a significant difference in ROM during the combing and reach to back pocket tasks after surgery may be due to capsular stiffness. A recent study from the American Shoulder and Elbow Surgery Open Meeting by Murrell et al. (2017) found an overall 24% reduction in shoulder movement at 6, and 12 weeks, with full recovery at 24 weeks. This indicates ROM decreases initially after surgery, taking longer to gain ROM back. Our study may still be too early in the current study to see significant differences in ROM. They also found shoulders which were stiff before surgery were more likely to be stiff at 6, 12, and to a lesser extent at 24 weeks. However, stiffer shoulder pre-operatively and at 6 and 12 weeks had better rotator cuff integrity at 6 months after repair. The results for this study indicate no statistical change in ROM in the TH joint; meaning the repaired shoulder has reached its PLOF, but has yet to advance past the pre-operative ROM status toward full ROM. This may be due to transient posterior capsular stiffness which was not investigated or recorded in this study. The same study (Murrell et al., 2017) suggested an initial capsular thickness occurs after surgery, but over time decreases back to the uninjured, contralateral shoulder at 6 months. The window for this study, 3 months, may be too early to see changes in ROM due to the increase amount of posterior capsule thickness occurring at this point in time during the rehabilitation process.

No statistical significance in abduction at this point in time may be due to the subjects' position within the rehabilitation process. At the post-operative window, subjects were seen between 9 and 12 weeks. During this point in time, the subjects have completed at least 8 weeks of rehabilitation (subtract 1 week post-surgery) according to the surgeon's rehabilitation protocol (Appendix E). At 8 weeks, subjects are just allowed to perform active ROM to the affected shoulder and gentle isometrics in a pain free range. By 10 weeks, subjects are allowed to begin progressive resistive exercises with the goal of meeting pre-injury status with stretching as needed. The subjects may be participating in activities not desired by the surgeon or therapist at this point in time (i.e reaching overhead). They also may not be attending rehabilitation sessions at all or fail to follow instructions by their therapist such as completing their home exercise program. A recent study by Ahmad, Haber, and Bokor (2015) compared rehabilitation adherence and re-tear rates and found the poorest adherence to be between 6 and 12 weeks post-opertively with a 11.8 % re-tear rate, compared to 0-6 week rate of 13.4% and 12-26 week rate of 3.9%. Our 3 month window could be capturing the part of rehabilitation where patients are not complying to their rehabilitation protocol. One should note, those who participate fully in their rehabilitation program are not guaranteed better success rates or function than those who do not adhere to protocols; however, studies have shown adherance and re-tear rates may be correlated

(Ahmad et al., 2015) and rehabilitation adherance is a key factor for repair success (Ahmad et al., 2015; Nho et al., 2009; Verma et al., 2010).

Although not statisticaly significant, differences of 14.52° in internal/external rotation ROM during the crossbody task pre-operatively (90.75°) to post-operatively (105.27°) (*p*= 0.0120) ocurred. A statisitcally significant difference of internal/external rotation from pre-to-post operative repair during the crossbody task might be more prevelant with a larger population. From speculation, it may be due to the increased integrity of the supraspinatus muscle. Although the primary function of the supraspinatus is to abduct the humerus, it also helps support the humerus during a combined movement of shoulder flexion and internal rotation (Ackland & Pandy, 2011), the main TH joint movements during the crossbody task. Fritz et al. (2017) indicated the primary motions after supraspintus tears may not be significant, but the accessory motions may be more relevant after surgery. That would support what is happening during the crossbody task as shoulder flexion and internal rotation are a secondary motion of the supraspinatus to stabilize the humeral head inside the GH joint during these motions.

Aim 2: Pre-operative Surgical and Non-Surgical Shoulders

From the GEE statistical analysis, no statistically significant differences in ROM means occured. There was no statistically significant difference of the TH joint abduction/adduction ROM between the surgical (41.94°) and non-surgical (49.80°) shoulder pre-operatively. This may be occurring due to the surgical group needing to be further divided based on tendon involvement. Although this study proposed to recruit a homeogenous sample population of supraspinatus tears only, it consented three subjects with more than a supraspintus tear (subjects # 5, 7 and 8). These subjects have more than one tendon tear which may be affecting the results found in the current study. When the groups are split apart by number of tendons involved

(Figure 10), Group A (supraspinatus only) has about a 15 degree difference between their surgical and non-surgical shoulder. The opposite is occurring for Group B (supraspinatus and other tendons) because their surgical ROM to perform the combing task is greater than their non-surgical ROM. When both groups are compared to the total group average, the differences may not be as pronounced and therefore, not statistically significant.

These findings may be supported by the concepts of stability and mobility at the glenohumeral joint. For example, it was previously stated the GH joint is supported by the rotator cuff musculature for stabilization. When injury occurs, such as a RC tear, the cuff becomes less stable due to the disruption of supporting musculature. This results in greater instability which could lead to increased mobility among the joint. Therefore, those with more than one RC tear may be more instable and mobile. This may support the findings that subjects with multi-tendon involvement have increased ROM (group B). Other literature has found that multi-tendon involvement has lead to differences in structural and clinical outcomes in chronic tears as compared to single tendon involvement (Jost, Pfirrmann, & Gerber, 2000; Nho et al., 2009; Oh et al., 2009). This further supports that individuals with multi-tendon tears have different kinematics than single-tendon tears.

Aim 3: Pre-operative and Post-operative ASES Scores

Although there were no statistically significant differences between the scores pre-to-post operatively, five of eight subjects increased their score. This may be clinically significant because 62.5% of subjects increased their perceived shoulder function by the 3 month follow up window. Also, 2 of the 8 (25%) subjects scored higher than 80 on the ASES, with a higher score indicating greater shoulder function. A statistical difference between scores may not be seen at this point during the rehabilitation process because studies have found an increased score after 1 or more years after the initial repair (Baumgarten, Chang, Dannenbring, & Foley, 2018; Ravindra, Jones, & Bishop, 2017; Vora et al., 2018). These studies found lower median pre-operative ASES scores (41) as compared to the current subjects' (57.5). Post-operatively, the median ASES score was 95 at an average of 3.7 years (2.01-7.47 years) follow up. Another study (Vora et al., 2018) found ASES scores at 1 year follow up to be 77.43 as compared to the current study's 3 month follow up scores (59.9). Another sudy found similar results do pre-operative ASES scores (42.3) and post-operative scores (91.9) at a year follow up (Ravindra et al., 2017). The current study's post-operative window may be too soon during the rehabilitation process to see a significant change in the group's average ASES scores as indicated by the previous two studies that showed a longer follow up produces a higher score. A future study with a 1+ year follow up may elicit better results for a statistical change in ASES scores. The literature supports most people reaching high ASES scores after 1 year indicating perceived shoulder function returns. The ASES is designed to rate the difficulty one has with each ADL, which can provide pertinent information to occupational therapists helping retrain the person with a rotator cuff repair. The ASES is a valid outcome measure with two domains of pain and function; however, the ASES does not allow subjects to rank the most difficult tasks which leads to decreased performance in their affected shoulder. Higher functioning patients may experience a ceiling effect due to the response structure of the assessment (Angst et al., 2004).

Currently, there is no known literature that investigates post-operative pain scores within the window of 9-12 weeks using the VAS. Most studies have highlighted long term affects of pain at 1 or 2 year follow ups or short term during the hospital stay. According to the VAS scores of the subjects who participated in the current study (Figure 16), subjects may be experiencing mild pain (average score of 3/10) that may be limiting their ability to perform the three ADL tasks of this study. A small percentage of patients have persistent shoulder pain and limitations post-operatively. Ravindra et al. (2017) found variables correlated to increased pain (VAS scores) post-operatively: pre-operative narcotic use, higher pre-operative VAS scores, lower scores on the Western Ontario Rotator Cuff (WORC) index and WORC emotional section. These findings indicate emotional and mental health may play a part in sustained pain after rotator cuff repair. Although a mental health questionnaire was not used for this study, it may play a large role in one's ability to manage pain and participate in activities. Since patients can have pain for an extended period of time after the surgery,only one follow up window at 9-12 weeks may not be an accurate picture of how pain limits their abilities over time. According to the VAS (Figure 16), the group's pain rating decreased after surgery. This may support why the scores for the ASES slightly increased after surgery due to the decrease in pain. When pain decreases, subjects may perceive their shoulder at a higher physical ability indicating they can perform more functional tasks. Virk et al. (2017) found people equally valued pain relief and strength return before and after surgery. Before surgery, increasing age was associated with stronger preferences for pain relief.

The success of rotator cuff repairs is dependent on many factors highlighted throughout this paper. Healing, as described by Mall, Tanaka, Choi, and Paletta (2014) is the formation of a continuous layer of tissue from the RC muscle belly to its insertion on the greater tuberosity. In recent literature, patient related factors affecting the healing rates of RC have been identified as demographic, (patient age, duration of symptoms, and longer follow ups), co-morbidity-status, and tear-related factors. Co-morbidities including Diabetes Mellitus, hypercholesterol, smoking status, and NSAID use have been shown to affect and delay bone-tendon healing (Chung, Oh, Gong, Kim, & Kim, 2011; Lundgreen et al., 2014; Mall et al., 2014; Meyer, Wieser, Farshad, & Gerber, 2012). Tear-related factors affecting poor healing have included large tears with longer duration of symptoms and multi-tendon involvement (Tashjian, Hung, Burks, & Greis, 2013).

They found small to medium sized tears had higher healing rates (87%) compared to large to massive-sized tears (62%). They identified lower healing rates in multi-tendon tears (36%) compared to 67% of single-tendon tears (Tashjian et al., 2010).

Conclusions

This work successfully quantified TH joint kinematics during three ADL tasks. It investigated the difference of ROM in abduction/adduction during the combing task, internal/external rotation during the crossbody task, and flexion/extension during the reach to back pocket task. It also compared the difference of abduction ROM during the combing task pre-operatively between the surgical and non-surgical shoulders. When pre-to-post-operative ASES scores were compared, the findings may indicate supraspinatus repair may not be determined by abduction motions, but secondary motions during stability. No difference in abduction/adduction ROM during the hair comb task and flexion/extension ROM during reach to back pocket may be due to capsular tightness. The significant findings of internal/external rotation during the crossbody task may be due to the supraspinatus' ability to perform rotator cuff stability during these motions. No difference between pre-operative abduction/adduction ROM between the surgical and non-surgical shoulders could be due to a group wash out effect. Subjects may need to be analyzed by number of tendons involved in the future to better understand the kinematics investigated. No difference between pre-and-post scores of the ASES may be due to the follow up window being too soon in the rehabilitation process to determine a difference in perceived shoulder performance. This work may aide clinicians in the rehabilitation of performing ADLs before and after rotator cuff surgery. These results indicate each subject has many factors that influence their success and function after surgery. It is imperative therapists collect data from the patient before surgery on the type of tear, tendons involved, pain, activity level, health status (i.e. smoking), symptom onset, etc. to ensure the most optimal care for post-surgical rehabilitation. The results of this study indicate patients may have different shoulder function after surgery based on PLOF. Future directions of this research should investigate the entirety of the shoulder workspace including the other joints, possible muscle activation among the rotator cuff muscles with longer follow up windows to better understand the length of recovery.

Aim 1:

- Hypothesis A: The TH joint abduction/adduction ROM will be different pre-operatively compared to post-operatively for the combing task.

Findings: There was no statistical difference pre-to-post-operatively for abduction/adduction ROM during the combing task.

- Hypothesis B: The TH joint internal/external ROM will be different pre-operatively compared to post-operatively for the crossbody task.

Findings: There was no statistical difference pre-to-post-operatively for internal/external ROM during the crossbody task.

- Hypothesis C: The TH joint flexion/extension ROM will be different pre-operatively compared to post-operatively for the reach to back pocket task.

Findings: There was no statistical difference pre-to-post-operatively for flexion/extension ROM during the reach to back pocket task.

Aim 2:

- Hypothesis 1: There will be a statistical difference pre-operatively between the surgical and non-surgical abduction/adduction ROM during the combing task.

Findings: There was no statistical difference pre-operatively between the surgical and non-surgical abduction/adduction ROM during the combing task.

Aim 3:

- Hypothesis 1: There will be a statistical difference between pre-to-post-operative ASES scores as a group.

Findings: There was no statistical difference between pre-to-post-operative ASES scores as a group.

III. Conclusion

Summary

The findings may indicate supraspinatus repair may not be determined by abduction motions, but secondary motions during stability. No difference in abduction/adduction ROM during the hair comb task and flexion/extension ROM during reach to back pocket may be due to capsular tightness. The significant findings of internal/external rotation during the crossbody task may be due to the supraspinatus' ability to perform rotator cuff stability during these motions. No difference between pre-operative abduction/adduction ROM between the surgical and non-surgical shoulders could be due to a group wash out effect. Subjects may need to be analyzed by number of tendons involved in the future to better understand the kinematics investigated. I recommend that subjects be classified by tendon-involvement prior to ROM comparisons. No difference between pre-and-post scores of the ASES may be due to the follow up window being too soon in the rehabilitation process to determine a difference in perceived shoulder performance.

The goal of skilled occupational therapy intervention is to rehabilitate the patient back to their prior ability before disease or injury occurred. Results of this study may provide evidence to support why occupational therapists should be seeing patients before surgery. A pre-operative session with an OT would entail an extensive questionnaire to pinpoint the patient's current level of function, pain profile, pre-operative objective measurements such as ROM and strength, and the chance to education the patient on what to expect after surgery. The OT would educate the patient on the purpose of surgery, precautions, donning/doffing sling, and post-operative exercises. After the surgery, the therapist would then have prior knowledge of their shoulder ability, cognition, learning style, and overall needs of the patient when coming in for post-operative therapy. A well-educated patient is necessary for optimal results from a RC repair creating less cost for the patient and healthcare system while decreasing chance of re-admittance.

Limitations

This study is limited by the number of participants recruited (8 subjects). However, since this study is a pilot study to quantify movement of the upper extremity, it serves the purpose of the study. Eight subjects should be a large enough sample to still find significant statistical differences between joint kinematics. A major limitation is that subjects were not solely chosen with a single tendon, supraspinatus tear. Subjects had other tears: Subject 5 and 8 had a subscapularis tear and Subject 10 had a multi-tendon tear involving the subscapularis and infraspinatus along with the supraspinatus. Another limitation includes not having the subjects follow a strict rehabilitation protocol throughout the study. The subjects recruited were provided a standard rehabilitation protocol from the surgeon but were not followed up on during the rehabilitation process; therefore, subjects completed the rehabilitation phase with different therapists and rehabilitation protocols. Although all subjects underwent post-operative rehabilitation, this study did not control the location, practitioner, or protocol of therapy each subject received. The researchers cannot make definitive accusations of repair and rehabilitation outcomes. Fatigue is also a limitation that should be addressed due to lack of rest between trials and tasks. There are no rest periods built into testing, but the contralateral arm did perform each task and allowed the surgical arm to rest as the nonsurgical arm performed the ADL task. Also, only three ADLs were investigated in this study which does not represent the full capacity of how people with rotator cuff tears perform all their everyday activities. The UE custom model, designed by (Schnorenberg et al., 2014), was validated for wheelchair users; tasks performed above 120 degrees may be inaccurate due to lack of clarity of marker placement. The markers may be too close together during these tasks to fully capture the movement segments in the shoulder region.

Future Directions

This pilot study provides the opportunity to expand the investigation of UE kinematics and functional outcomes of people with rotator cuff tears during ADLs. Numerous research questions have surfaced from the findings of this work. For instance, topics that needs further investigation include compensation strategies before and after surgery in all joints of the shoulder complex, measuring functional independence with ADLs before and after surgery, and muscle recruitment or activation of the RC muscles before surgery compared to after surgery.

Further evaluation of muscle activation and compensatory motions within the shoulder relative to all joints of the UE should be identified to understand muscle recruitment. There is evidence to support an increase in deltoid activation as a compensatory method during arm elevation with particular increase in lower elevation angles (McCully, Suprak, Kosek, & Karduna, 2007; F Steenbrink et al., 2006). The deltoids generate an increased force to compensate lost abduction force from a torn supraspinatus, which causes an increased upward force on the humeral head (F. Steenbrink, de Groot, Veeger, van der Helm, & Rozing, 2009). Also, using EMG and musculoskeletal modeling, F. Steenbrink, Meskers, Nelissen, and de Groot (2010) found an increase in deltoid activation with an increase in moment loading in those with rotator cuff tears than controls. Furthermore, very recent literature from Dyrna et al. (2018) investigated 12 (mean age 67 years) cadaveric shoulders during deltoid activation and maximum abduction for various tear patterns (i.e. intact, isolated supraspinatus, anterosuperior subscapularis, etc.) and found considerable compensatory deltoid function to prevent abduction movement loss from a tear. They concluded that rotator cuff tears put more strain on the deltoid muscles to prevent abduction motion loss regardless of tear size. According to a recent abstract presented at the International Shoulder Group (ISG) conference this past August, based off anatomical evidence suggesting the supraspinatus and infraspinatus muscle is composed of distinct sub-regions (S. Y. Kim et al., 2007) Calver (2018) investigated the activity of these sub-regions in vivo during dynamic, isokinetic shoulder movements using fine wire EMG. Although no significant differences were found for the supraspinatus, the infraspinatus demonstrated a higher contribution of the superior region during fast exertions compared to slow and during external rotation compared to abduction. The opposite occurred for the middle region of the infraspinatus. Similarly, another recent study by Cudlip (2018), from ISG, investigated the anterior and posterior regions of the supraspinatus during elevation tasks and found larger ranges of activation in the anterior region compared to the posterior region, with higher activity closer to the sagittal plane (flexion/extension). This work provides enhanced information on supraspinatus recruitment strategies.

Also, future studies should have a larger, more homogenous sample of specific tendon involvement. Implementing a control of healthy subjects may make our comparison stronger. Furthermore, future studies should investigate pain using the VAS, or other validated measuring scale, to quantify how pain affects ADL function before and after a task in people with rotator cuff tears. There is little information on how people with rotator cuff tears perform their ADLs before and after repair. Future studies should focus on measuring independence through valid independence measures such as the Functional Independence Measure (FIM). Investigating ADL independence in people who have rotator cuff tears will provide disease specific information to therapists on their function. Studies could go further into investigating which tasks seem to be more strenuous before and after surgery, indicated on the Borg scale, so occupational therapists know which ADLs impact their function the greatest. This would help identify the order of tasks patients may wish to work on during their rehabilitation session and overall plan of care.

Functional tasks, instead of simulated tasks, are the best way to evaluate the UE are reduce performance variability (Taylor, Kedgley, Humphries, & Shaheen, 2018). Taylor et al. (2018) investigated if simulated tasks replicate the movement of functional tasks in 14 healthy subjects. It was conlcuded that simulated ADL tasks were not accuratley replicated and functional tasks should be used for UE movement during ADLs. Future studies should include tasks that are more functional. The crossbody task used in this study is supposed to simulate dressing, but only has the injured arm reach to the opposite shoulder. This is not a functional task, as the subject did not use a shirt to simulate putting their arm through the clothing to complete the task. Also, the reach to back pocket task is a simulation of toileting. Actual toilet care should be performed in the future to make the task as functional as possible. The combing task was the only real, functional task as it asked for the subject to hold a plastic comb and pretend to comb their hair. Having the comb run through their hair may be more realistic and more functional.

Current investigation of the UE kinematic shoulder complex is underway with intent to investigate all UE joints such as the elbow, wrist, and torso with ROM and stability tasks. A longer follow up window of 22-30 weeks after rotator cuff repair is also being added to the study to better understand the rehabilitation process. Also, EMG data will be collected on 8 UE muscles (bilateraly) to measure activiation and on/off time during each task. This will allow researchers to better understand recruitment strategies during specific tasks.

Self-Reflection

If I were to do this study again, I would have made some changes. Although this was a pilot study with various components to the study, I would have made a longer follow up window, added the Functional Independence Measure (FIM) and Rotator Cuff Quality of Life (RCQOL) tools as additional outcome measures, had all subjects homogenous, and made them follow the same rehabilitation protocol. A longer follow up window would make sense because other research has shown improvements of the UE at least a year after surgery. If I wanted to understand quality of life specific to rotator cuff tear, I could use the RCQOL measure. Also, having a homogenous population allows for generalization of results to a group. In the future for recruitment, patients should be homogenous with only a supraspinatus tear to decrease factors influencing their recovery. All subjects only having the supraspinatus muscle involved allows the investigator to be more confident in their conclusions. Not controlling for the rehabilitation protocol is the largest limitation of this study because the therapy could influence the rotator cuff tear success; however, following strict a single rehabilitation protocol may not be feasible and realistic of for each patient due to their individual plans of care. It would be more appropriate when the study is investigating differences in rehabilitation protocols and how that affects rotator cuff repair. Each patient did receive the same protocol from the orthopaedic surgeon to bring to therapy, but was not tracked for follow through.

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Appendix A: Consent Form

UNIVERSITY OF WISCONSIN – MILWAUKEE

CONSENT TO PARTICIPATE IN RESEARCH

Rotator Cuff Repair Subject Consent

This Consent Form has been approved by the IRB for a one year period

1. General Information

Study title:

Pre-Operative versus Post-Operative Kinematic And Muscle Activation Assessment Of The Upper Extremity Following Rotator Cuff Repair

Person in Charge of Study (Principal Investigator):

PI: Brooke Slavens, PhD

2. Study Description

You are being asked to participate in a research study. Your participation is completely voluntary. You do not have to participate if you do not want to.

There are three main purposes of this study:

1) Determine compensatory motions of upper body joints used during recovery from rotator cuff repair by evaluating joint motions and muscle activity.

2) Demonstrate increased range of motion in upper extremity joints on the affected (i.e. torn or repaired rotator cuff) side comparing pre and post-surgical motion.

3) Determine rotator cuff muscle forces pre- and post- operatively with muscle activity and upper body musculoskeletal simulation techniques to show increased rotator cuff recruitment with increased recovery time.

Why the study is being done:

Rotator cuff repair is a common intervention for tears of the rotator cuff. However, few studies have focused on the motions used by patients after surgery to compensate for the recovering shoulder affected by the tear. This study's focus is to identify compensatory motions by evaluating joint motions, muscle activity, and muscle/joint forces that result from compensating for the recovering shoulder. This data will further the knowledge of the effects of rotator cuff repair and provide evidence on how to better rehabilitation protocols and improve patient education on care of the recovering rotator cuff.

The data gathered from recording the motion on your upper extremities during specific activities of daily living (ADLs), range of motion (ROM) tasks and stability tasks will help our team define the compensatory motion used during recovery from rotator cuff repair.

Where is the study being done?

Mobility Laboratory, Innovation Accelerator Building

1225 Discovery Parkway

Wauwatosa, WI 53226

How many subjects will participate in the study locally and at all sites?

Twenty (20) subjects at UWM's Mobility Laboratory

How much time will each subject need to commit in terms of hours and days?

Each subject will be tested on four different days, for no more than 5 hours per day. The first day of testing will occur 1-3 months prior to surgical intervention, while the other three remaining days will occur 9-12 weeks, 5-7 months, and 8-10 months after rotator cuff repair surgery.

3. Study Procedures

What will I be asked to do if I participate in the study?

The study consists of four (4) different test days with a maximum of five (5) hours each day. The first testing day will occur 1-3 months prior to rotator cuff repair surgery. The remaining three test days will occur 9-12 weeks, 5-7 months, and 8-10 months post-surgery. Testing will be conducted at the UWM Mobility Lab. Your contact information (cell-phone and/or home phone) will be collected and used to contact you within a week of your test days to remind you of your testing schedule.

Each day of testing will start with the collection of three shoulder health and surgical outcomes scores for the affected shoulder: 1) Modified Constant-Murley 2) UCLA and 3) Simple shoulder Test.

You will be asked prior to the study to bring clothing appropriate for motion testing of the upper extremity (e.g. tank-top). This will allow placement of muscle sensors and reflective markers on the skin of the upper extremity. You may come to UWM Mobility lab dressed for testing or may dress in the patient room attached to the laboratory. If you require assistance getting dressed, someone of the same sex will be available to help you.

Multiple measurements will then be taken prior to testing (height, weight, lengths of different limbs, etc.). Reflective markers and muscle activity sensors will be placed over specific locations on your body using double-sided tape. The markers and sensors will be placed on both upper limbs (hands, forearms, arms), as well as your chest, neck, and back. To ensure accurate muscle activity recordings, skin where the muscle activity sensors are placed may need to be shaved.

A 15 camera motion analysis system will be used to capture body motions during three (3) activities of daily living (ADLs), six (6) range of motion (ROM) tasks, and five (5) stability tasks. All tasks will be performed while standing. All tasks will be demonstrated and explained prior to testing.

The ADLs:

- Combing hair with comb
- Reaching across the body
- Reaching to perineum or back pocket (hygiene)

ROM tasks:

- Maximum shoulder forward flexion
    - You will raise your arm straight out in front of you, as high as possible
- Maximum shoulder extension
    - You will raise your arm straight back, behind you, a far as possible
- Maximum shoulder internal rotation
    - With your shoulder and elbow bent to 90 degrees you will rotate your hand to the left, in front of your body
- Maximum shoulder external rotation
    - With your shoulder and elbow bent to 90 degrees you will rotate your hand to the right, away from your body as far as possible
- Maximum abduction
    - With a straight arm, you will raise your arm straight out to the side as high as you can
- Maximum abduction in the scapular plane
    - With a straight arm, you will raise your arm straight out to the side between straight in front of you and straight out to the side

Stability Tasks:

- Lift up to 3 lbs from your waist up to a shelf placed in front of you
- Lift up to 3 lbs from eye-level down to a shelf placed in front of you
- Lift up to 3 lbs from your waist up to a shelf placed to the side of you
- Lift up to 3 lbs from eye-level down to a shelf placed to the side of you
- Perform external rotation of the shoulder while holding up to 3 lb

All tasks will be performed 5 times. You will be allowed to rest at any time during the study.

Why is each task necessary for this research?

The activities listed represent common daily tasks. Analysis of these motions will help identify common compensatory motions used during the ADLs among patients with rotator cuff tear/repair. Additionally, the reaching tasks will allow us to determine how well patients with rotator cuff pathology can utilize the space around them.

How long will each task take for the subject to complete?
A single testing session will take 4-5 hours to complete. Specifically

- Subject preparation (body measurements, marker and sensor application) – 45-60 minutes
- Shoulder health and surgical outcomes measures (3 surveys: Modified Constant-Murley, UCLA, Simple Shoulder Test)- 30-60 minutes
- Motion Capture (5 to 10 minutes per task, with breaks taken as needed)- 2-3 hours

Will my patient chart be accessed for the study?

Yes, your patient chart will be accessed during the study to monitor the progress of your surgery. Only data related to shoulder health will be accessed.

Will video/photographic recordings be done?

Yes, photos and video will be collected throughout testing.

If the subject refuses to be recorded, can they still participate?
Yes

4. Risks and Minimizing Risks

What risks will I face by participating in this study?

- Though rare, the tape used to mount sensors and reflective markers may cause irritation
- Task repetition may induce muscle fatigue of the upper body
- Technique used to perform task may also cause muscle fatigue of the upper body.

What measures are included in the study design to minimize these risks?

- Tape used to mount reflective markers and sensors will be applied and removed carefully. Skin irritation from the tape is similar to that of a band-aid, and should be gone after a couple hours
- At any time during the study, you may ask to take a break to prevent fatigue. You will also be asked if you would like to take a break periodically during the study.
- You will be provided a short verbal description of the task prior to performing the task. If you feel you are unable to perform the task at any time (even while performing the task) you may stop the task.

Psychological and Social Risks:

We do not anticipate that you will experience any psychological or social risks

5. Benefits

Will I receive any benefit from my participation in this study?

. You will be compensated for study participation as detailed in the section below “Study Costs and Compensation”. Otherwise there are no direct benefits for participating in the study other than furthering research on the effects of rotator cuff tear and repair.

6. Study Costs and Compensation

<u>Will I be charged anything for participating in this study?</u>

You will not be charged for participating in this study.

<u>Are subjects paid or given anything for being in the study?</u>

You will be compensated $50/day, for a total $200 upon completion of the 4 days of testing. This compensation will be provided to the subject in the form of a check, mailed from MCW. You will be required to fill out a W-9 form, which requires the collection of your social security number (SSN), for compensation. Your SSN will not be used for study purposes, only for your compensation

7. Confidentiality

<u>What happens to the information collected?</u>

All identifiable data will be kept in a locked filing cabinet in a secured room at the UWM Mobility Lab at the UWM Innovation Accelerator Building. All other coded data will be kept on password protected computers and external hard drives. Data will be destroyed after 7 years. Data will be presented as de-identified group averages.

We may decide to present what we find to others, or publish or results in scientific journals or at professional conferences.

8. Alternatives

<u>Are there alternatives to participating in the study?</u>

You may decline to participate in this study at any time.

9. Voluntary Participation and Withdrawal

What happens if I decide not to be in this study?

Your participation in this study is entirely voluntary. You may choose not to take part in this study. If you decide to take part, you can change your mind later and withdraw from the study. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with the University of Wisconsin Milwaukee, and will not impact the care of you receive or relationship with your physician.

What will happen to the subject's data if the subject withdraws or is withdrawn early?

We will use the information collected.

10. Questions

Who do I contact for questions about this study?

For more information about the study or the study procedures or treatments, or to withdraw from the study, contact:

Brooke Slavens, PhD

UWM Innovation Accelerator Building

Rehabilitation & Motion Analysis Laboratory

1225 Discovery Parkway, Room 140

Wauwatosa, WI 53226

Phone: (414) 316-3093

Who do I contact for questions about my rights or complaints towards my treatment as a research subject?

The Institutional Review Board may ask your name, but all complaints are kept in confidence.

Institutional Review Board

Human Research Protection Program

Department of University Safety and Assurances

University of Wisconsin – Milwaukee

P.O. Box 413

Milwaukee, WI 53201

(414) 229-3173

11. Signatures

Research Subject's Consent to Participate in Research:

To voluntarily agree to take part in this study, you must sign on the line below. If you choose to take part in this study, you may withdraw at any time. You are not giving up any of your legal rights by signing this form. Your signature below indicates that you have read or had read to you this entire consent form, including the risks and benefits, and have had all of your questions answered, and that you are 18 years of age or older.

____

Printed Name of Subject/ Legally Authorized Representative

____ ______________________

Signature of Subject/Legally Authorized Representative Date

Preferred Contact Method for Testing Days:

By providing your cell phone number and/or home number, we will be able to remind you of your scheduled test days 1 week prior to your scheduled testing.

___________________Cellphone Number

___________________Home Phone Number

Research Subject's Consent to Audio/Video/Photo Recording:

It is okay to photograph and videotape me while I am in this study and use my photographs and videotaped data in the research for publications and presentations, without obscuring my face.

Please initial: ____Yes ____No

if no, answer the additional question:

It is okay to photograph and videotape me while I am in this study and use my photographs and videotaped data in the research for publications and presentations, only if my face is obscured.

Please initial: ____Yes ____No

Principal Investigator (or Designee)

I have given this research subject information on the study that is accurate and sufficient for the subject to fully understand the nature, risks and benefits of the study.

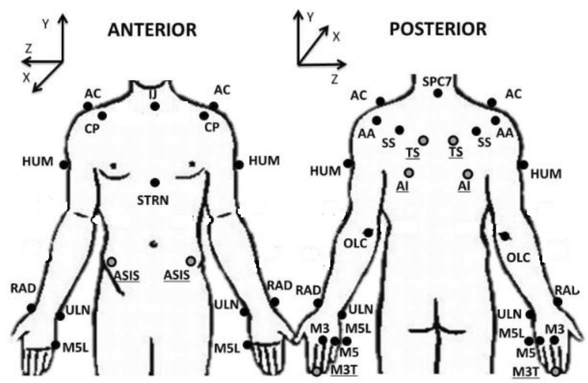
____ ______________________

Printed Name of Person Obtaining Consent Study Role

____ ______________________

Signature of Person Obtaining Consent Date

Appendix B: UE Biomechanical Model



#	Marker	Description	Check
1	IJ	Sternal notch, between sternal clavicular heads	
2	L.CP	Left coracoid process, bony prominence inferior to acromioclavicular head, feel with downward rotation of scapula	
3	R.CP	Right coracoid process, bony prominence inferior to acromioclavicular head, feel with downward rotation of scapula	
4	L.AC	Palpate clavicle, follow laterally towards shoulder joint. Contiue past the acromial-clavicular joint, toward prominence which is directly above the shoulder joint. Have patient AB/adduct to confirm	
5	R.AC	Palpate clavicle, follow laterally towards shoulder joint. Contiue past the acromial-clavicular joint, toward prominence which is directly above the shoulder joint. Have patient AB/adduct to confirm	
6	STRN	Xihpoid process, most inferior portion of the sternum	
7	L.HUM	Place on lateral border of arm, stright line from acromium to lateral humeral epicondile	
8	R.HUM	Place on lateral border of arm, stright line from acromium to lateral humeral epicondile	
9	L.RAD	Bony prominence, superior to thumb, on lateral wrist. Abduct/adduct wrist to confirm, place parallel to ULN	
10	R.RAD	Bony prominence, superior to thumb, on lateral wrist. Abduct/adduct wrist to confirm, place parallel to ULN	
11	L.ULN	Bony prominence, superior to 5th metacarpal (pinky), on lateral wrist. Abduct/adduct wrist to confirm, plar parallel to RAD	
12	R.LUN	Bony prominence, superior to 5th metacarpal (pinky), on lateral wrist. Abduct/adduct wrist to confirm, plar parallel to RAD	
13	L.M3	Dorsal side of hand, 3rd knuckle, place with hands relaxed (i.e. open)	
14	R.M3	Dorsal side of hand, 3rd knuckle, place with hands relaxed (i.e. open)	
15	L.M5	Dorsal side of hand, 5th knuckle, place with hands relaxed (i.e. open)	
16	R.M5	Dorsal side of hand, 5th knuckle, place with hands relaxed (i.e. open)	
17	SPC7	Most prominent spinous process of the spine posteriorly, have subjet touch chin to chest to to confirm while palpating	
18	L.TS	Palpate scapula, medial angle of scapula. Trace from anterior angle across spine going medially, should end before reaching spine	
19	R.TS	Palpate scapula, medial angle of scapula. Trace from anterior angle across spine going medially, should end before reaching spine	
20	L.SS	Place along scapular spine between TS and AA markers	
21	R.SS	Place along scapular spine between TS and AA markers	
22	L.AA	Palpate acromium, palpate posteriorly to scapular spine. Trace spine laterally until most prominent. Flex/Extend arm to confirm	
23	R.AA	Palpate acromium, palpate posteriorly to scapular spine. Trace spine laterally until most prominent. Flex/Extend arm to confirm	
24	L.AI	Palpate scapula following medial border to most inferior point. Ab/adduct the arm to confirm.	
25	R.AI	Palpate scapula following medial border to most inferior point. Ab/adduct the arm to confirm.	
26	L.OLC	Most prominent process of distal ulna. Flex/extend elbow to confirm	
27	R.OLC	Most prominent process of distal ulna. Flex/extend elbow to confirm	
28	L.ASIS	Palpate Iliac crest (most lateral and suprior portion of the pelvis), follow crest medial and inferiorly until bone tapers, place on last palpated prominence	
29	R.ASIS	Palpate Iliac crest (most lateral and suprior portion of the pelvis), follow crest medial and inferiorly until bone tapers, place on last palpated prominence	
30	L.3DMCP	Place on nail of 3rd digit	
31	R.3DMCP	Place on nail of 3rd digit	

Appendix C: Data Collection Sheet

SUBJECT DATA

De-identified Subject Number: Date:

Testing Session: Pre-operative: ____________Weeks before surgery

Post-operative: ___________Weeks after surgery

Date of Birth: Dominant side (circle): R L Surgical Side (circle): R L

Weight (lb): Height (inches):

Elbow Diameter (olecranon to elbow pit- anterior/posterior direction) (cm):

a. Right =
b. Left =

Hand width (thickness – anterior/posterior direction) (cm):

a. Right =
b. Left =

ADLs

ADL	Vicon Trial Name	EMGWorks Trial Name	Comments
Reach to Back: RIGHT	R_Back_01		
	R_Back_02		
	R_Back_03		
	R_Back_04		
	R_Back_05		
	R_Back_06		
	R_Back_07		
Reach to Back: LEFT	L_Back_01		
	L_Back_02		
	L_Back_03		
	L_Back_04		
	L_Back_05		
	L_Back_06		
	L_Back_07		

ADL	Vicon Trial Name	EMGWorks Trial Name	Comments
Comb: RIGHT	R_Comb_01		
	R_Comb_02		
	R_Comb_03		
	R_Comb_04		
	R_Comb_05		
	R_Comb_06		
	R_Comb_07		
Comb: LEFT	L_Comb_01		
	L_Comb_02		
	L_Comb_03		
	L_Comb_04		
	L_Comb_05		
	L_Comb_06		
	L_Comb_07		

ADL	Vicon Trial Name	EMGWorks Trial Name	Comments
Crossbody: RIGHT	R_Crossbody_01		
	R_Crossbody_02		
	R_Crossbody_03		
	R_Crossbody_04		
	R_Crossbody_05		
	R_Crossbody_06		
	R_Crossbody_07		
Crossbody: LEFT	L_Crossbody_01		
	L_Crossbody_02		
	L_Crossbody_03		
	L_Crossbody_04		
	L_Crossbody_05		
	L_Crossbody_06		
	L_Crossbody_07		

Appendix D: ASES Shoulder Assessment

SHOULDER EVALUATION ☐ Initial ☐ Follow-up Test Date:

Affected Shoulder: Right Left

Please answer the follow questions:

Rate the pain in your shoulder on a scale of 0 – 10
(0 means no pain at all and 10 means pain as bad as it can be)

0 1 2 3 4 5 6 7 8 9 10

Rate the difficulty level of the following activities for your shoulder:

Put on a coat
Not difficult Somewhat difficult Very difficult Unable

Sleep on our affected side
Not difficult Somewhat difficult Very difficult Unable

Wash back/attach bra in back
Not difficult Somewhat difficult Very difficult Unable

Managing toileting
Not difficult Somewhat difficult Very difficult Unable

Comb hair
Not difficult Somewhat difficult Very difficult Unable

Reach a high shelf
Not difficult Somewhat difficult Very difficult Unable

Lift 10 pounds above the shoulder
Not difficult Somewhat difficult Very difficult Unable

Throw a ball overhead
Not difficult Somewhat difficult Very difficult Unable

Do usual work
Not difficult Somewhat difficult Very difficult Unable

Do usual sport of recreational activity
Not difficult Somewhat difficult Very difficult Unable

Appendix E: Post-Operative Rehabilitation Protocol

Arthroscopic/Mini Open/ Open Rotator Cuff Repair

Rehabilitation Protocol, Dr. Grindel, M.D.

Medical College of Wisconsin & Froedert Hospital

Standard Rotator Cuff Repair

<u>Post Op:</u>

- Sling or immobilizer to be worn at all times with ice pack to shoulder (20 minutes on; 20 minutes off).
- Remove sling 4-5 times per day for gentle Codman's (move body, not arm).
- Active Range of Motion (AROM) to scapula, elbow, forearm, wrist, and hand

<u>One Week Post Op:</u>

- Can remove sling at home, continue use in public
- Passive Range of Motion (PROM) all planes with minimum goal by 6 weeks as follows:
    - Shoulder flexion = 90º - 100º
    - Abduction = 90º - 100º
    - Internal Rotation = 60º - 75º
    - External Rotation = 60º - 75º
- *This is a minimum; may increase to full passive range of motion as tolerated.
- Edema control
- Postural education
- Soft tissue mobilization
- Monitor range of motion to uninvolved joints (scapula, elbow, forearm, wrist, and hand).
- Home program: Codman's, active range of motion to uninvolved joints, passive range of motion to shoulder (by family member or closed chain).
- Hot packs as needed. Ultrasound (to muscle belly, NOT repair site).

<u>Six Weeks Post Op:</u>

- Continue passive range of motion with goal of full range of motion in all planes by 8 weeks.
- Begin active assist range of motion - pulleys, cane, wall walks.
- May use HVPC or TENS as needed.

<u>Eight Weeks Post Op:</u>

- Gentle submaximal isometrics to affected shoulder in pain free range.
- Active range of motion to affected shoulder.
- Continue modalities and soft tissue mobilization as needed.

<u>Ten Weeks Post Op:</u>

- Continue modalities and soft tissue mobilization as needed.
- Begin progressive resistive exercises with goal to meet pre-injury status.
- Stretching as needed
- Monitor scapular stability.

-

Massive Rotator Cuff Tear Repair

Post Op:

- Sling or immobilizer to be worn at all times
- Ice pack (20 minutes on; 20 minutes off).
- Remove sling 4-5 times per day for gentle Codman's (move body, not arm)
- Active Range of Motion (AROM) to scapula, elbow, forearm, wrist, and hand
- Precaution: NO active range of motion to shoulder; no passive external rotation > neutral or extension

One Week Post Op:

- Passive Range of Motion (PROM) all planes with minimum goal by 6 weeks as follows:
  - Shoulder flexion = 90º - 100º
  - Abduction = 90º - 100º
  - Internal Rotation = 60º - 75º
  - External Rotation = 60º - 75º
- *This is a minimum; may increase to full passive range of motion as tolerated.
- **If subscapular tenodesis, limit external rotation to 30º.
- Edema control
- Postural education
- Soft tissue mobilization
- Monitor range of motion to uninvolved joints (scapula, elbow, forearm, wrist, and hand).
- Home program: Codman's, active range of motion to uninvolved joints, passive range of motion to shoulder (by family member or closed chain).
- Hot packs as needed. Ultrasound (to muscle belly, NOT repair site).

Eight Weeks Post Op:

- Continue passive range of motion with goal of full range of motion in all planes by 8 weeks.
- Begin active assist range of motion - pulleys, cane, wall walks.
- May use HVPC or TENS as needed.

Ten Weeks Post Op:

- Gentle submaximal isometrics to affected shoulder in pain free range.
- Active range of motion to affected shoulder.
- Continue modalities and soft tissue mobilization as needed.

Twelve Weeks Post Op:

- Continue modalities and soft tissue mobilization as needed.
- Begin progressive resistive exercises with goal to meet pre-injury status.
- Stretching as needed
- Monitor scapular stability.

Appendix F: Statistical Anlaysis

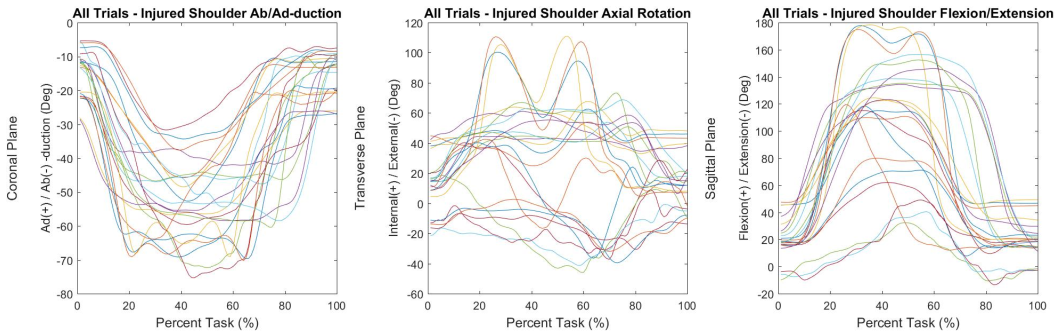
Aim 1				
Task	Pre-Operative	Post-Operative	Difference	*p*-value
Hair Combing	41.12	42.33	1.21	0.7817
Crossbody	38.05	34.87	14.52	0.012
Reach to Back Pocket	89.55	104.07	-3.18	0.1513

Aim 2				
Task	Pre-Operative	Post-Operative	Difference	*p*-value
Hair Combing	42.31	50.39	8.08	0.1728

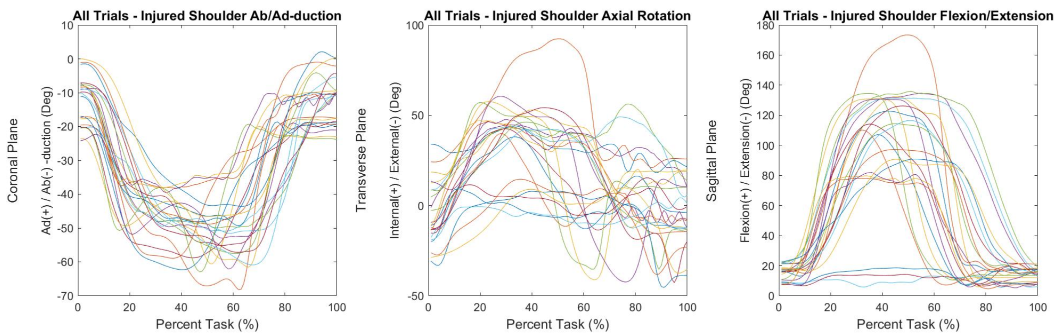
Aim 3				
	Pre-Operative	Post-Operative	Difference	*p*-value
ASES Score	57.45	59.93	2.49	0.0209

Appendix G: Individual Trials per Task

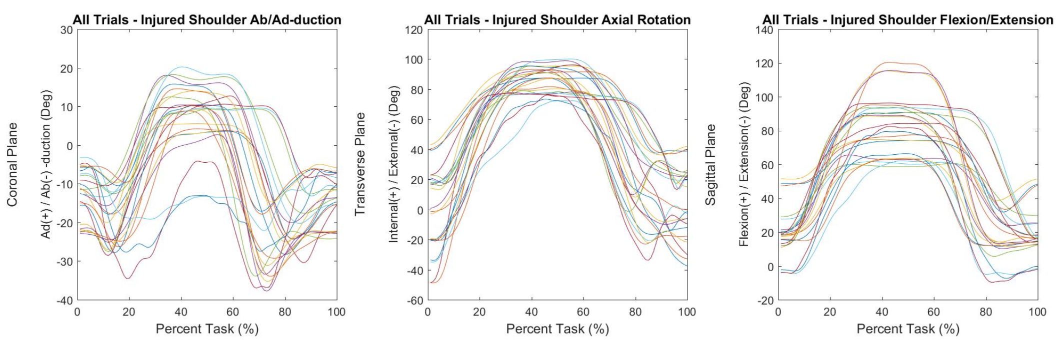
Pre-Operative Hair Combing Task



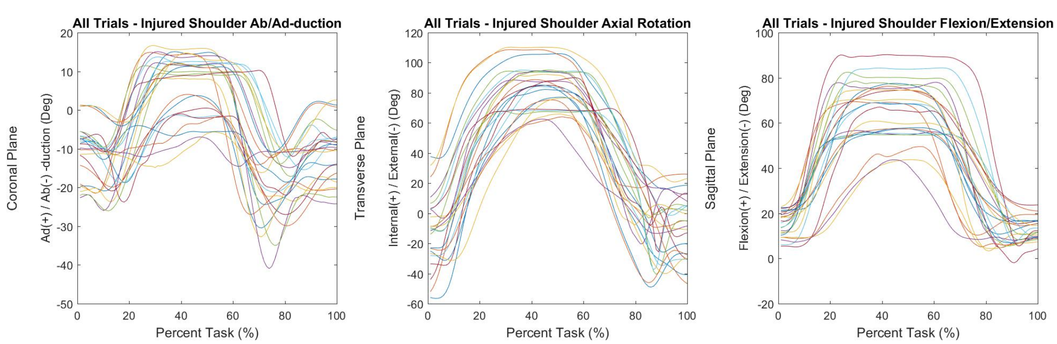
Post-Operative Hair Combing Task



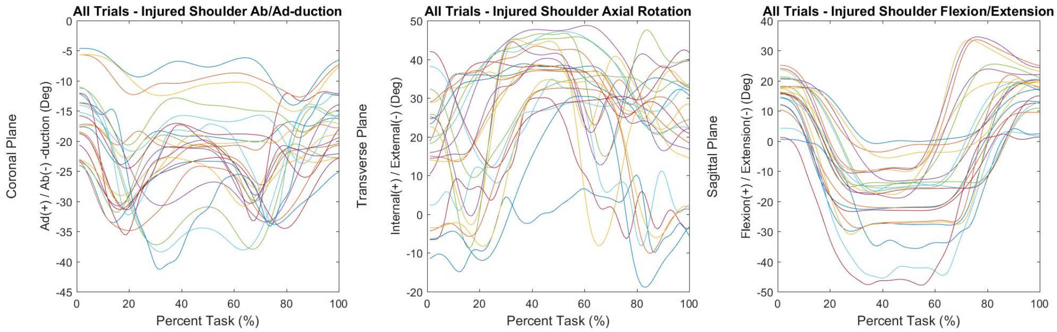
Pre-Operative Crossbody Task



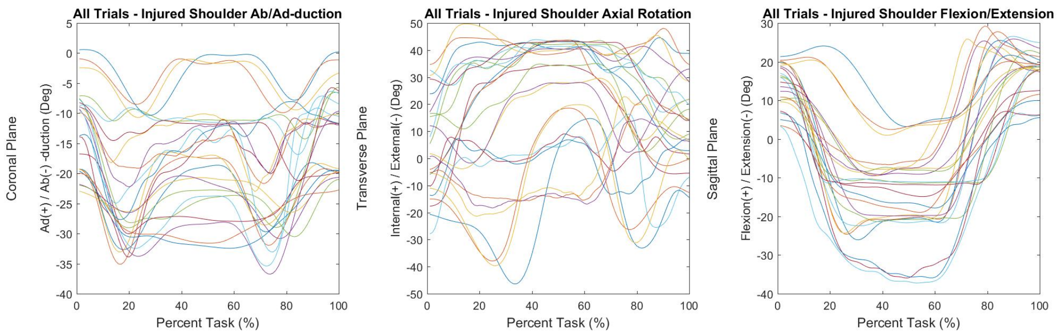
Post-Operative Crossbody Task



Pre-Operative Reach to back pocket Task



Post-Operative Reach to back pocket Task



Appendix H: ASES Scores and Responses

ASES Scores and Responses

Subject	Visit	NPS	Put on a coat	Sleep on your affected side	Wash your back/do a bra	Manage toileting	Combing your hair	Reach a high shelf	Lift 10 lbs above your shoulder	Throw a ball overhand	Do your usual work	Do usual sport or recreational activity	Score
1	Pre-Op	5	ND	SD	ND	ND	ND	SD	VD	SD	SD	ND	64.9
	Post-Op	0	ND	U	ND	ND	ND	SD	U	SD	SD	ND	84.9
2	Pre-Op	2	SD	VD	VD	ND	ND	VD	VD	VD	ND	SD	70
	Post-Op	0	ND	ND	VD	ND	ND	ND	VD	VD	ND	VD	86.6
3	Pre-Op	4	SD	U	SD	ND	ND	SD	VD	VD	SD	VD	58.3
	Post-Op	5	SD	U	U	ND	VD	SD	U	U	SD	U	16.6
4	Pre-Op	6	SD	SD	SD	SD	SD	VD	VD	VD	ND	SD	49.9
	Post-Op	2	SD	VD	VD	SD	ND	SD	SD	VD	VD	VD	66.6
5	Pre-Op	8	SD	VD	SD	SD	SD	VD	VD	VD	SD	U	33.3
	Post-Op	6	SD	U	U	VD	VD	SD	U	U	SD	U	33.3
6	Pre-Op	3	VD	VD	VD	SD	ND	SD	SD	VD	SD	VD	61.6
	Post-Op	4	SD	VD	VD	SD	SD	SD	VD	SD	VD	VD	58.3
7	Pre-Op	3	SD	VD	VD	SD	SD	SD	VD	VD	SD	VD	60
	Post-Op	2	SD	SD	SD	ND	SD	SD	U	SD	-	SD	68.3
8	Pre-Op	5	SD	SD	SD	ND	ND	SD	SD	SD	SD	SD	61.6
	Post-Op	3	SD	SD	SD	ND	ND	SD	U	U	SD	SD	64.9

Appendix I: OT Summit of Scholars Abstract

Glenohumeral Joint Kinematics and Functional Outcomes Scores for ADL Task Following Supraspinatus Rotator Cuff Repair

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Introduction: Approximately one quarter of U.S. adults will have a rotator cuff (RC) tear in their lifetime, and about 300,000 RC repair surgeries are performed annually. RC tears can impede physical function, such as one's ability to perform activities of daily living (ADLs), and maintain functional independence. While studies have compared post-operative thoracohumeral (humerus relative to thorax) joint kinematics of various populations, there is no known research assessing upper extremity (UE) joint kinematics of ADLs pre- and post-operatively, which may provide insight on the rehabilitation process. The purpose of this study is to compare shoulder function and glenohumeral (GH) joint kinematics during a combing task before and after supraspinatus repair surgery.

Methods: Six adult subjects (63.5 ± 7.1 years) with a full-thickness, supraspinatus RC tear completed two sessions: 0-12 weeks before surgery and 9-12 weeks after surgery. The validated Simple Shoulder Test (SST) and the University of California-Los Angeles (UCLA) shoulder test were administered to assess perceived shoulder function. A 15-camera Vicon T-series motion analysis system (Oxford Metric Group, Oxford, UK) tracked 27 reflective markers on the upper extremities (UE) during 5 combing trials. A custom biomechanical model was used to calculate the GH joint angles (humerus relative to scapula) in the 3 anatomical planes. The Wilcoxon signed-ranks test compared pre-operative to post-operative sessions ($p < 0.05$) via IBM SPSS Statistics (IBM, Armonk, NY).

Results: There was a statistically significant decrease in GH joint external rotation range of motion pre-operatively (72.9° ± 26.9°) to post-operatively (46.3° ± 16.0°) ($p= 0.028$). This is due to the significant decrease in maximum external rotation angle from 83.8° ± 24.8° pre-operatively to 56.2° ± 18.6° post-operatively ($p = 0.028$). When combing the hair, less external rotation, while abducted, increases the subacromial space, thereby reducing the risk of shoulder impingement. Despite the group improvement of these metrics, 2 individuals were unable to independently complete the task post-operatively. There were no statistically significant differences for the SST and UCLA scores, yet for the question on the UCLA regarding satisfaction with the affected limb, five subjects reported an increase post-operatively.

Conclusion: We were able to successfully compare GH joint kinematics during hair combing and shoulder assessments before and after a RC repair surgery. Although patients may be able to perform ADLs independently before surgery, they may be using altered kinematics and compensation strategies due to injury and pain. A comparison of the pre-operative to post-operative performance may influence appropriate rehabilitation after surgery. Research is underway to investigate shoulder motion, pain, and function in a larger population with additional ADLs. Ultimately this work may aid occupational therapists in ADL interventions to improve rehabilitation outcomes and increase independence.

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Appendix J: RESNA Abstract

A comparison of glenohumeral joint kinematics and functional outcomes in adults with rotator cuff tear

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INTRODUCTION

Approximately one quarter of U.S. adults will have a rotator cuff (RC) tear in their lifetime, and about 300,000 RC repair surgeries are performed annually [1]. The supraspinatus is the most commonly torn rotator cuff muscle requiring surgical repair [2]. RC tears can impede physical function, such as one's ability to perform activities of daily living (ADLs), and maintain functional independence [3,4]. The American Occupational Therapy Association defines ADLs as the tasks of taking care of one's own body [5]. The goal of surgical repair is to decrease pain, increase range of motion (ROM), and allow return to the workforce [6]. Although patients may be able to perform ADLs independently before surgery, they may be using altered kinematics due to injury and pain. While studies have compared post-operative thoracohumeral (humerus relative to thorax) joint kinematics of various populations, there is no known research assessing upper extremity (UE) joint kinematics of ADLs pre- and post-operatively, which may provide insight on the rehabilitation process. [7,8]. The purpose of this study is to compare glenohumeral (GH) joint kinematics of three ADLs and shoulder function before and after supraspinatus repair surgery. It is hypothesized that GH joint kinematics and functional shoulder outcomes will be significantly different following rotator cuff surgery.

METHODS

Subjects

Six (6) adult subjects (63.5 ± 7.1 years) with a full-thickness, supraspinatus RC tear participated in this study (Table 1). Subjects who had a previous shoulder surgery, currently have systemic inflammatory arthritis, or shoulder pathology in both shoulders were excluded. This study was approved by the University of Wisconsin-Milwaukee (UWM) Institutional Review Board; written informed consent was obtained from each participant.

Table 1. Subject and supraspinatus tear characteristics (mean ± 1 standard deviation)

Subj ect	Gen der	Surgi cal Arm	Domina nt Arm	Tear Thickn ess	Tear Size (cm)	Age (years)	Pre session to Surgery (days)	Surgery to Post session (days)
1	F	R	R	Full	1.25	59	34	78
2	M	L	R	Full	1.50	75	2	85
3	F	L	R	Full	1.00	55	19	71
4	M	R	R	Full	1.00	66	4	79
5	F	R	R/L	Full	2.50	66	9	76
6	M	R	R	Full	4.00	60	5	80
Aver age ± SD					1.9 ± 1.2	63.5 ± 7.1	12.2 ± 12.2	78.2 ± 4.6

Data collection

Each subject completed two sessions; 0-12 weeks before surgery and 9-12 weeks after surgery with an average of 78 days post-surgery. The validated Simple Shoulder Test (SST) [9] and the University of California-Los Angeles (UCLA) shoulder test were administered to assess perceived shoulder function. A higher score indicates better shoulder function for both assessments. The SST is a 12-item assessment with yes/no responses with a maximum score of 12. The UCLA, also a self-reported outcome, has a maximum possible score of 35; a score less than 27 indicates fair/poor shoulder function, while a score greater than 27 indicates good shoulder function [10,11]. A 15-camera Vicon T-series motion analysis system (Oxford Metric Group, Oxford, UK) tracked 27 reflective markers on the upper extremities (UE) during three ADL tasks: combing the hair, reaching to the back pocket, and reaching across the body (Figure 1). Each subject started with their arm resting at their side, performed the ADL, and ended with their arm back at their side. Subjects were instructed to perform all tasks to the best of their ability.

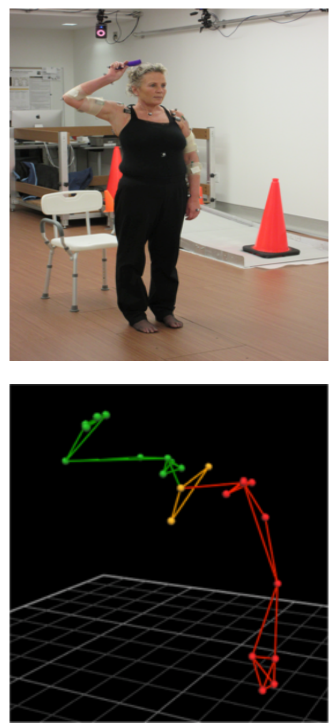


Figure 1. Participant (top) performing the combing task on surgical side with the upper extremity marker set [12] with the corresponding Vicon image (bottom).

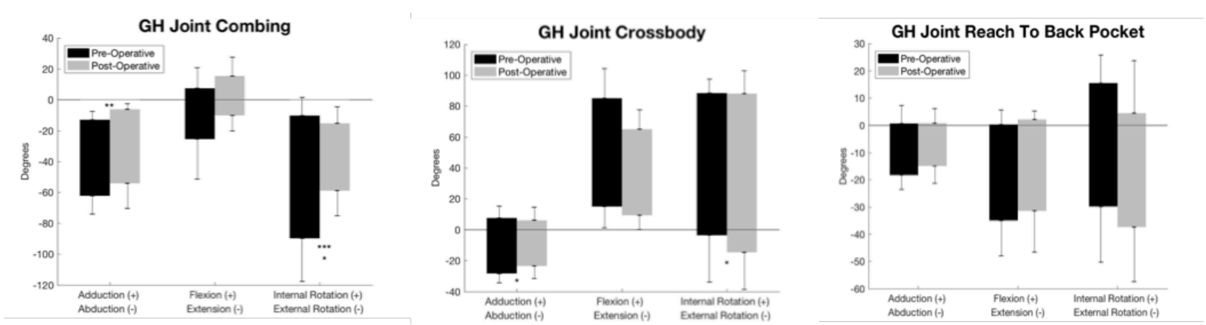
Data processing

All data was processed using Vicon Nexus Software to label marker trajectories, fill gaps, and filter the data (Figure 1). A custom inverse dynamics model [12] was used to calculate the three-dimensional (3-D) upper extremity joint kinematics. The 3-D GH joint angles were calculated as the motions of the humerus relative to the scapula. Peak angles and ranges of motion (ROM) were determined for each trial, and the group means and standard deviations were computed for each task. The Wilcoxon signed-ranks test, a nonparametric statistical procedure, compared pre-operative to post-operative sessions ($p < 0.05$) via IBM SPSS Statistics (IBM, Armonk, NY).

RESULTS

Glenohumeral joint kinematics

There was a statistically significant decrease in GH joint external rotation range of motion pre-operatively (79.4° ± 22.8°) to post-operatively (43.6° ± 15.4°) (p= 0.028) during the combing task (Figure 2a). This is due to the significant decrease in maximum external rotation angle from 89.6° ± 27.6° pre-operatively to 58.9° ± 16.3° post-operatively (p = 0.028)(Figure 2a). The average minimum abduction angle was significantly different pre (13.0°± 5.4°) to post 6.2°± 3.5°, p= 0.028) to complete the combing task. For the crossbody task (Figure 2b), the average maximum abduction angle was decreased significantly from pre (37.2°± 13.4°) to post (25.2°± 11.8°, p=0.028), while the average maximum external rotation angle increased significantly pre-operatively (41.5°± 29.3°) to post-operatively (50.1°± 26.7°, p=0.028). There were no significant differences in kinematics during the reach to the back pocket ADL task (Figure 2c).



(a) **(b)** **(c)**

Figure 2. Mean glenohumeral joint pre-operative (black) vs. post-operative (gray) average peak angles during ADL tasks in each plane with ± 1 standard deviation bars. One asterisk (*) indicates significant difference (p-value < 0.05) in average maximum angle, two asterisks (**) indicates significant difference in average minimum angle, and three asterisks (***) indicates significant difference in average ROM. (a) Combing task. (b) Reach to back pocket task. (c) Cross-body task.

Shoulder functional outcomes

While there was no significant difference between the group average SST scores pre (5.8 ± 2.6) to post (4.8 ± 3.2, p=0.343). Although there were no significant differences in the SST scores within the group, subject 2's score did increase to 9 post-operatively (Figure 3). Although there was no significant difference between the group average UCLA scores pre (16.3 ± 4.6) to post (20.7 ± 5.7, p=0.144), there was substantial individual variability. Three subjects' scores increased (subjects 2, 4 and 5), two stayed the same (subjects 1 and 3) and 1 decreased (subject 6) (Figure 3). Additionally, for the UCLA question regarding satisfaction with the affected limb, five subjects reported an increase post-operatively. Active forward flexion on the UCLA scores averaged 129.2° at 9-12 weeks post-operatively.

DISCUSSION

To our knowledge, this is the first work that compares biomechanics of the shoulder and shoulder function outcomes pre-and post-supraspinatus repair. We successfully characterized glenohumeral joint motion and functional performance in six patients.

We examined ADLs to evaluate functional performance. We found a significant difference in GH joint external rotation ROM and a decreased maximum abduction angle during the combing task. When combing the hair, less external rotation, while abducted, increases the subacromial space, thereby reducing the risk of shoulder impingement. Although we found differences in external rotation ROM, a recent study found differences in internal rotation during the combing task [7]. Patients may still retain independence with functional tasks pre and post-operatively even if they do not achieve what is considered full shoulder ROM. A study conducted on healthy females found the minimum angles required to perform the combing hair task were 73 degrees of GH scaption, 38 degrees of GH external rotation, and 112 degrees of elbow flexion [13]. Although obtaining full motion is a reasonable goal by therapists for shoulder treatment, less ROM may be sufficient to perform functional tasks and still be independent. Significant differences were found in the average maximum abduction angle (decrease) and maximum external rotation angle (increase) for the combing task. Subjects' ROM was the same, but they may be reallocating ROM amongst different planes to still complete the task. After surgery, the mechanics of the joint may change during the recovery process when structures have been restored to their original function.

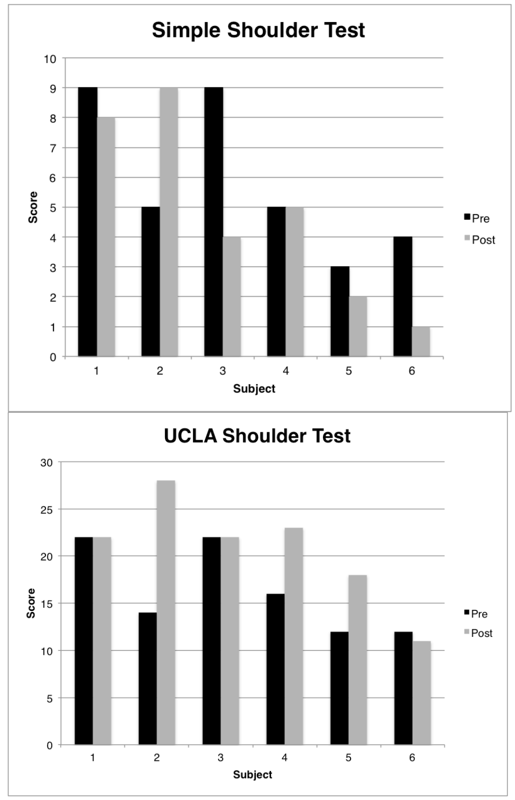


Figure 3. Individual subjects' pre-operative (black) and post-operative (gray) scores of the SST and UCLA functional shoulder assessments.

We found no significant differences in the SST score at 9-12 weeks, which is similar to other findings of subjects not improving at this point in time [14,15]. Healthy subjects scored within the range of 9 to 12, so subject 2's post-operative score of 9 indicates they reached healthy shoulder function range [16]. Although it depends on the physician and clinic, most current rehabilitation protocols suggest patients have full active ROM by post-operative week 12. Mean UCLA item scores of active forward flexion (129.2°) demonstrates patients are close to recovering almost full range of motion of the allowed 180 degrees (71.8%). Pre-operative knowledge could help therapists identify a change in intervention or rehabilitation protocols to benefit those who are not progressing as well as other patients. Other factors to consider in future analyses are age, duration of symptoms, tear size, and pre-post window time.

CONCLUSION

We were able to successfully compare GH joint kinematics during three ADLs and shoulder assessments before and after a RC repair surgery. Although patients may be able to perform ADLs independently before surgery, they may be using altered kinematics and compensation strategies due to injury and pain. A comparison of the pre-operative to post-operative performance may influence appropriate rehabilitation after surgery. Research is underway to investigate shoulder motion, pain, and function in a larger population with additional ADLs. Ultimately this work may aid occupational therapists in ADL interventions to improve rehabilitation outcomes and increase independence.

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