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BIOPSYCHOLOGICAL PREDICTORS OF PAIN AND FUNCTION IN PATIENTS WITH ROTATOR CUFF CONDITIONS

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BIOPSYCHOLOGICAL PREDICTORS OF PAIN AND FUNCTION IN PATIENTS WITH ROTATOR CUFF CONDITIONS

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
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By

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ABSTRACT OF DISSERTATION

BIOPSYCHOLOGICAL PREDICTORS OF PAIN AND FUNCTION IN PATIENTS WITH ROTATOR CUFF CONDITIONS

Predicting worse patient-reported outcomes in those with Rotator Cuff (RC) conditions is dependent on examining both biological and psychological impairments. In order to help determine which biopsychological factors are associated with pain and function in patients with RC related conditions and to determine who may be at an increased risk for worse outcomes after Reverse Shoulder Arthroplasty (RSA), biopsychological associations between patient demographics, scapular motion, humeral motion, RC tear size, pain associated psychological distress, and function were clinically evaluated to investigate prediction models for pain and function. The central hypothesis is that in a group of patients with symptomatic Cuff Tear Arthropathy (CTA), increased scapular motion and increased psychological distress will predict worse American Shoulder and Elbow Surgeon (ASES) pain and function one-year after RSA. In 50 patients with RC tears, we used the pain, function, and the total outcome components of the ASES to examine which biopsychological factors are associated with each component of the ASES score. Additionally, 17 patients with CTA were examined to determine which biopsychological factors predicted each final score of the ASES one year after RSA. The principle finding of this study is that a multivariate approach examining clinical biopsychological factors in patients with RC tears is necessary to better understand clinical components leading to ASES pain, function, and total scores.

KEYWORDS: Rotator cuff, Biopsychological, Reverse Shoulder Arthroplasty,
Cuff Tear Arthropathy, American Shoulder and Elbow Surgeon

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Chapter 1: Introduction

1.1 Background

The prevalence of rotator cuff (RC) tears increases with age and with a rising trend of an ageing population, the importance of research in this area will continue to rise.[1] Since the surgical rates of RC repairs has risen 200% over the recent years, it is imperative that research continues to seek out evidence that will inform clinical treatment decisions in this patient population.[2,3] If RC tears are left untreated they can lead to glenohumeral osteoarthritis (GHOA) and eventually result in a Cuff Tear Arthropathy (CTA).[4,5] Unbalanced muscle forces occur in the presence of a large rotator cuff tear causing progressive degeneration of the articular cartilage and subchondral bone at the glenohumeral joint.[6] GHOA is characterized by progressive wear on the glenoid and humeral bone.[7] Further degradation of the RC tear results in more serious mechanical disruption at the shoulder joint resulting in CTA.[4] Three main descriptive features of CTA are 1) RC insufficiency, 2) glenohumeral articular changes, and 3) superior migration of the humeral head.[8] CTA is a painful and debilitating condition that negatively disrupts a patients quality of life. Therefore, monitoring and assessing patients with RC tears at risk for CTA is warranted to optimally manage this chronic condition.

Shoulder motion requires an intricate balance between mobility and stability to achieve functional upper extremity motion.[9] Passive stability is provided by capsuloligamentous structures within the joint while dynamic stability includes the use of muscle-activity, including the RC, to help prevent unbalanced forces.[10,11] This complex system is necessary for maintaining normal shoulder motion but renders the joint prone to injury and difficult to treat. Preoperative shoulder motion is one major factor that can affect outcomes after surgical repair of the RC.[12] Functional recovery after nonoperative or operative treatment is dependent on the current status of shoulder motion which is why it tends to be the focus of rehabilitation regimens.[13,14] Motion in the shoulder is not limited to movement of the humerus but also depends on the contribution of scapular motion against the thoracic cage.[15] Assessing and quantifying scapular motion is necessary to objectively understand how its multidimensional movement patterns can affect upper extremity function in the presence of a RC tear.

The scapula provides a stable base of support allowing for efficient shoulder function to occur in accordance with coordinated activity of the RC and surrounding muscles.[16] Motion of the scapula during humeral elevation occurs in three planes, 1) coronal, 2) sagittal, and 3) transverse.[17] To quantify triplanar motion of the scapula, 3-Dimensional (3D) biomechanical analysis are most commonly used but these devices are not clinically friendly, require extensive training, and are costly.[17-20] Scapular assessment is clinically used as an indicator for shoulder pathomechanics but is typically assessed in only one or two planes due to limitations in current reliable and valid measurement devices available.[21-28] Visual observation of the scapula is a clinically common reliable method that has been validated against 3-dimensional testing for identifying scapular movement patterns but is limited to a 2-level (yes/no) classification..[29-32] This 2-dimensional classification limits the 3-dimensional quantification of scapular motion.

In patients with RC tears, scapular motion has been shown to be directly affected by RC tear size.[10,33-35,36,37] Scibek et al. found that as RC tear size increases, so does scapular upward rotation during arm elevation.[33] The author suggests this is due to scapular compensation needed to execute arm elevation. Furthermore, the literature supports that scapular compensatory motion exists in patients with symptomatic RC tears compared to those without pain, resulting in greater scapular motion during arm elevation.[38,39] Unfortunately, these identified biological measurements of the scapula in patients with RC tears have all been conducted using 3D motion analysis or 3D modeling software. Moreover, these scapular measurements have only been assessed during arm elevation which limits biomechanical understanding of scapular motion to one single arm movement. Clinical data of scapular motion and measurements taken during other important functional arm movements, such as shoulder external rotation, are necessary for a clinician to comprehensively understand how scapular motion contributes to shoulder dysfunction.

Injury to the shoulder due to a RC tear not only alters the anatomical system but also changes an individual's psychology in response to the injury.[40,41] Disability of the shoulder due to a RC tear can lead to an inability to do work or perform activities of daily living, such as household tasks, which has further implications on psychological stability.[42] The biopsychological model has been supported in the literature as a model that helps guide treatment decisions, inform medical practice, and optimizes outcomes.[43-46] Kroner-Herwig et al. used the biopsychological model and found that pain and sex held the highest prognostic values for predicting the recurrence of headaches and back pain in young adults.[43] In orthopaedics, it is common that functional outcomes after treatment are limited to measurements of biological functions but this disregards a patient's emotional well-being in regards to their physical activity.[47] Patient reported outcome measurement tools are used to quantitatively inform clinicians about the health status of a patient that considers both an individual's biological and psychological state.[48]

A reliable, valid and responsive outcome measure used in patients with RC related conditions to determine shoulder pain and function is the American Shoulder and Elbow Surgeon (ASES) assessment form.[49] The ASES contains sections for self-report of pain and functional measures created for patients with shoulder pathologies.[50] In patients with RC conditions, the ASES has acceptable internal consistency (0.64), construct validity ($p < 0.05$), responsiveness to change (1.16), and acceptable floor (0%) and ceiling effects (0%). Kocher et al also found appropriate criterion validity ($p < 0.05$) between the total ASES score and the physical functioning, role-physical, and bodily pain domains of the Short Form-12 scale but not with the role-emotional, mental health, vitality, and social function domains.[49] In patients undergoing shoulder surgery for a RC tear, the ASES has been preoperatively associated with established psychological assessment forms. Thorpe et al[51] reported that ASES scores were significantly worse in patients with low psychological functioning compared to high psychological functioning reported by the Pain Self-Efficacy questionnaire (PSEQ) ($p < 0.001$), Pain Catastrophizing Scale questionnaire (PCS) ($p < 0.001$), Tampa Scale of Kinesiophobia (TSK-11) ($p < 0.001$), and the Depression Anxiety and Stress Scale ($p < 0.001$). The author did not report the correlation value, making interpretation of correlation unknown.

Potter et al[52] found preoperative ASES differences ($p < 0.001$) when comparing between RC patients with and without distress assessed by the Distress and Risk Assessment Method form. Moreover, preoperative ASES scores have been shown to correlate with the physical component score of the Short-Form 36 (rho = 0.405) prior to shoulder arthroplasty.[53]

The experience of pain is shaped by both biological and psychological factors.[54] Pain does not correlate with severity of tear size ($p > 0.25$) but does negatively impact a patient's ability to maintain normal motion.[55] Unfortunately, the author did not report the correlation value which can make interpretation of correlation difficult. Minagawa et al. screened 664 individuals during a health care check-up and identified two times as many people with an asymptomatic RC tear compared to a symptomatic RC tear.[56] This highlights the complexity of RC conditions and that physical findings should not solely guide clinical decision making. Psychological distress related to pain catastrophizing[51], fear avoidance beliefs[57] , kinesiophobia[51], depression[58], anxiety[58], and pain self-efficacy[51] have been shown to be associated with lower preoperative patient reported scores but only depression ($p < 0.001$)[58,59] and anxiety ($p = 0.001$)[58] have been reported with high significance to predict less improvement in shoulder function after shoulder surgery.[51,52,58-62,63]

While psychological factors have been predictive of preoperative pain and postoperative outcomes in other shoulder injury patient populations, the role of these factors on patients undergoing reverse total shoulder arthroplasty for cuff tear arthropathy has not been assessed. The Optimal Screening for Prediction of Referral and Outcomes Yellow Flag (OSPRO-YF) form was developed to provide clinicians with a clinical tool used to comprehensively screen psychological impairments that are correlated with musculoskeletal conditions.[63] The OSPRO-YF has been validated to generate 11 pain-associated psychological distress scores in patients with musculoskeletal related shoulder pain.[64] These 11 psychological impairments include items taken from previously validated outcome tools for depression (PHQ-9), anxiety (STAI), anger (STAXI), fear avoidance beliefs for physical activity (FABQ-PA), fear avoidance beliefs for work (FABQ-W), pain catastrophizing (PCS), pain related fear of movement (TSK-11), pain related anxiety (PASS-20), pain self-efficacy (PSEQ), rehabilitation self-efficacy (SER), and chronic pain acceptance (CPAQ).[63] To optimize treatment outcomes, the literature supports that it is important to assess each one of these psychological components.

Treatment of RC related conditions is dictated by the patients age, severity of symptoms, radiographic findings, medical comorbidities, and patient characteristics.[65] When GHOA is associated with a massive rotator cuff tear, the center of rotation of the joint migrates upward and joint stresses become off-centered leaving the patient with CTA.[66] Surgical treatment of CTA has grown in the last decade as surgical options have expanded, and new surgical techniques have been introduced.[4] A total shoulder arthroplasty (TSA) is commonly used for patients with an intact rotator cuff, whereas a reverse shoulder arthroplasty (RSA) is reserved for patients with severe GHOA and CTA along with having a considerable amount of pain.[4] Improved function after RSA is typically a secondary goal of the surgical procedure and is less predictably achieved than pain relief.[4]

RSA was initially proposed in Europe in the 1970's and later re-conceptualized by Grammont in the 1980's.[67,68,69] This alternative surgical design reverses the shoulder anatomy by replacing a portion of the proximal humerus with a concave polyethylene socket and then implanting a half globe metal ball into the glenoid socket.[70] The Food and Drug Administration did not approve RSAs as a surgical option in the United States until 2003.[71] Since the approval, indications for RSA have continued to expand and include various degrees of cuff deficiency along with inflammatory arthritis, fracture sequelae, failed hemiarthroplasty, and infection.[70] The 2011 Nationwide Inpatient Sample dataset reported 21,692 RSA cases out of the 66,485 patients who underwent a shoulder arthroplasty in that year.[71] RSA is currently a well-established and effective surgical treatment for CTA since it addresses arthritis on both humeral and glenoid sides of the joint. Recent systematic reviews have found that long-term studies in general will report significant improvements in shoulder range of motion and patient reported function after RSA for CTA but each study has described clinical impairments in their results.[72,73] For example, 5 of the 7 studies reported by Ernstbrunner et al failed to restore shoulder external range of motion postoperatively.[72] Petrillo et al reported complications at 17.4% after RSA and were due to multiple factors such as prosthetic loosening, fractures, and dislocations.[73]

Problem

Predicting worse patient-reported outcomes in those patients’ undergoing RSA for CTA is dependent on examining both biological and psychological impairments. The ability to measure scapular motion objectively in the clinic is novel and potentially impacts patient-reported outcomes in patients with RC tears or CTA. The literature has failed to assess critical psychological constructs of pain related anxiety, pain related anger, self-efficacy associated with physical rehabilitation, and behavioral aspects of coping with pain in those with RC tears. Moreover, psychological constructs have not been preoperatively examined in patients undergoing RSA for CTA to help with predicting worse patient-reported outcomes. The inadequate clinical assessment of pain-associated psychological factors and lack of clinical measures in scapular motion makes it difficult to determine which biopsychological factors are more associated with pain or function thus making prediction of outcomes difficult for clinicians who treat patients with CTA. In order to help determine which biopsychological factors are associated with pain and function in patients with RC related conditions and to determine who may be at an increased risk for worse outcomes after RSA, biopsychological associations between patient demographics, scapular motion, humeral motion, RC tear size, pain associated psychological distress, and function need to be clinically evaluated to investigate prediction models for pain and function. This research project is designed to investigate these gaps.

Specific Aims and Hypotheses

In patients with RC tears, we will use the pain, function, and the total outcome components of the ASES to examine which biopsychological factors are associated with each component of the ASES score. Additionally, in those patients with CTA, we will assess which biopsychological factors predict each component of the ASES one year after RSA. The overall objective was to examine clinical biopsychological impairments and their role on pain and function in patients with small to massive RC tears to then help investigate prediction models for reporting worse pain and function one-year after RSA for CTA. The central hypothesis was that in a group of patients with symptomatic CTA, increased scapular motion and increased psychological distress would predict worse patient-reported shoulder pain and function one-year after RSA. To test our central hypothesis, the following specific aims were conducted.

Specific Aim 1: **Examine the association between clinical biopsychological impairments with pain, function, and total ASES score.**

This aim will test three hypotheses: 1) the combination of increased scapular anterior tilt during an arm flexion task and increased FABQ-PA will be significantly associated with lower ASES pain scores, indicating more pain 2) the combination of increased scapular upward rotation during an arm flexion task and decreased scapular external rotation during shoulder rotation by the side task will be significantly associated with lower ASES function scores, indicating worse function 3) the combination of increased scapular upward rotation during an arm flexion task and increased FABQ-PA scores will be significantly associated with lower total ASES scores, indicating worse pain and function. Significant findings suggest that in patients with a rotator cuff tear, physical and psychological factors are critical in explaining patient reported pain and function than a single factor. These results can then be used by health care providers to perform a more comprehensive examination of patients function that includes both psychological screening and clinical assessment of scapular motion to better examine a patients health status.

Separate multiple linear regressions with a forward stepwise approach will be used to determine which combination of the factors will be most associated with patient reported pain, function, and total ASES scores. A significant association between FABQ-PA and ASES pain scores would indicate that a patient’s fear avoidance behaviors of physical activity can directly influence how pain is experienced. Higher psychological distress can have negative implications in how well a patient responds to treatment. An initial treatment of behavioral therapy may help in reducing the amount of pain reported but future studies would be needed to determine this. A significant association between scapular motion compensation and ASES function scores would indicate that scapular motion contributes to the level of function a patient with a rotator cuff tear is reporting. Thus, clinical scapular motion should be considered a principal evaluative tool which has not been previously. As ASES scores are often used to represent a patient’s level of function both pre and post-operatively, identifying these relationships will begin to indicate the role biopsychological factors have on patient reported pain and function at any time point. The outcome of this aim will support the use of clinically examining both physical and psychological factors along with guiding future research in the application of a biopsychological focused treatment approach to improve pain and function.

Specific Aim 2: **Investigate a biopsychological model for predicting worse pain, function, and total ASES score one-year after RSA for CTA.**

The goal of the second aim is to establish which preoperative clinical biopsychological factors will predict patients who report worse pain, function, and total ASES scores one-year after RSA. This aim will test the following hypotheses: 1) increased FABQ-PA at initial evaluation will be most predictive of worse ASES pain scores, 2) increased scapular upward rotation at initial evaluation during an arm flexion task will be most predictive of worse ASES function scores, and 3) the combination of increased scapular upward rotation during an arm flexion task and FABQ-PA at initial evaluation will be predictive of worse total ASES scores one-year after RSA. Since it is the patient's subjective impression of their health status that is most important to the success of treatment it was decided that the ASES assessment score at 1 year would be most appropriate to use. A multiple linear regression will be utilized to determine which variables significantly contribute to reporting worse pain and functional outcomes one-year after RSA. Our biopsychological prediction model will allow physicians to adequately make clinical decisions and tailor preoperative treatment according to the severity of the pathology, pathomechanics, and psychological state of the patient. Surgical intervention certainly is impactful on patients but determining success or failure without better understanding the role of a patients physical and psychological well-being may not tell the complete story of a poor or successful surgical outcome in the eyes of the patient. Furthermore, our prediction model will be used to guide future intervention studies by providing researchers with specific biological and psychological impairments that need to be addressed prior to surgery in order to improve postoperative functional outcomes.

Operational Definitions

Biopsychological model: A perspective in which the study of the interconnection between physical features and human behavior is sought to understand their role on health and disease.

Biological: Physical factors that include rotator cuff tear size, range of motion of the scapula and the humerus in multiple planes.

Psychological: Behavioral factors that include depression, trait anxiety, anger, fear-avoidance beliefs for physical activity, fear-avoidance beliefs for work, pain catastrophizing, pain-related fear of movement, pain-related anxiety, pain self-efficacy, self-efficacy for rehabilitation, chronic pain acceptance behavior.

Percent scapular motion: The amount of scapular motion contributing to total arm elevation calculated by dividing degrees of scapular motion by degrees of arm elevation.

Cuff Tear Arthropathy (CTA): The combination of rotator cuff insufficiency, glenohumeral joint degeneration, and superior migration of the humeral head as evidence by radiographic or MRI findings.[4]

Reverse Shoulder Arthroplasty: Prosthesis designed to medially transfer the center of rotation of the humerus and lengthen the deltoid.[74] Key design elements:

1) Medially glenosphere

2) Lateralized humeral component

Assumptions

It will be assumed that:

1. All clinical measurements taken used the same techniques throughout each time point
2. All participants were truthful in their responses to the patient reported outcome measure, The American Shoulder and Elbow Surgeons assessment form
3. Assumptions associated with a multiple linear regression analysis

Limitations

1. No randomization of participants
2. Limited sample size

Delimitations

1. Participants were taken from a sample convenience at an outreach orthopaedic clinic
2. One surgeon used the same surgical technique with all operative patients
3. The use of a single prosthetic design consisting of a medialized glenosphere with a lateralized humeral component
4. Each RC tear was measured by a single musculoskeletal radiologist specialist
5. No strength measurements were use in any of the prediction equations

Chapter 2: Review of the Literature

Introduction

Rotator cuff conditions are considered one of the main underlying issues in elderly patients with shoulder pain and can lead to significant functional limitations.[5,75,76] The literature has highlighted the importance of evaluating physical and psychological components in the management of rotator cuff related disorders.[76-80] However, there are important physical and psychological measurements that still have not been clinically addressed in this patient population thus limiting the effectives of the examination process. The purpose of this literature review is to 1) describe the role of the rotator cuff muscle group for arm function, 2) discuss current evidence regarding how scapular kinematics are measured and affected by a rotator cuff condition, 3) explain the biopsychological model and how it relates to a critical patient reported outcome measure, the American Shoulder and Elbow Surgeons assessment form, 4) report existing research pertaining to currently known psychological constructs that are associated with patient reported outcomes in individuals who have rotator cuff related conditions, and 5) describe the epidemiology, indications for surgery, biomechanical effects, and surgical outcomes of a Reverse Shoulder Arthroplasty in patients preoperatively diagnosed with cuff tear arthropathy.

2.1 Functional Role of the Rotator Cuff

The rotator cuff (RC) is a group of four different muscles that each contribute to the dynamic stability of the glenohumeral (GH) joint.[10] These four muscles include the supraspinatus, infraspinatus, teres minor, and subscapularis.[81] Their attachments begin on the scapula and insert onto the humerus. When functioning properly, the RC assists in rotating the humerus with the help of the deltoid and other surrounding muscles to allow for functional arm movements.[82] This force coupling mechanism acts to draw the humeral head toward the glenoid to optimize deltoid force while the arm is abducting.[83] Moreover, the RC helps inhibit GH joint superior translation, activates before global muscles to allow for joint stability, and contributes to joint compression.[84] During frontal plane arm elevation the humerus will elevate and progressively externally rotate while the scapula is upwardly rotating, posteriorly tilting, and externally rotating. Since there is no single fixed center of rotation (COR) of the GH joint, the RC must continuously work together to neutralize forces.[10] A biomechanical study found that the direction and force applied by the RC muscle group is dependent on the position of the arm in space.[10] For example, Otis et al determined that during arm elevation the supraspinatus facilitates abduction and then external rotation at 60 degrees of arm elevation.[85]

Dysfunction of the Rotator Cuff

RC related disorders are one of the main underlying issues contributing to shoulder pain and dysfunction.[76] In an in-vivo study measuring compression of the RC, subjects were instructed to hold a 1-kg weight during arm elevation.[86] The results demonstrated that the amount of subacromial pressure on a RC was 1.5 times greater when the arm was in a high angle elevated position compared to at mid-range and by the side.[86] These mechanical features are important to understand and consider during clinical examination of a patient with shoulder pain and dysfunction that may be due to dysfunction in the RC. The supraspinatus and infraspinatus are reported as the most commonly injured RC muscles.[87] When lesions occur in these muscles, cadaveric studies found that distribution of load across the shoulder will change.[10] A few studies in patients with RC tears found that the upper trapezius (UT) was overactive.[83,88,89] An overactive UT can cause excessive scapular upward rotation which then results in superior translation of the GH joint's COR, thus leading to impingement of the RC.[83,88,89] Therefore, this may explain why increased scapular upward rotation is observed in the presence of a RC lesion.

If a partial thickness tear exists, the tendon is predisposed to further damage and is at an increased risk for progressing into a full-thickness tear.[90] This progression further compromises the stability of the GH joint and will lead to superior translation of the humeral head.[91,92] Superior migration is a critical biomechanical consequence that can be found radiographically and is a sign for RC deficiency.[93-95] Keener et al determined that a tear size >175 mm^2 had a very strong correlation ($r = 0.98 \pm 1.8$) with superior humeral head migration when compared to <175 mm^2 ($r = -0.08 \pm 1.3$).[39]

Magnetic Resonance Imaging of the RC

Evaluating the integrity of a RC is commonly conducted using Magnetic Resonance Imaging (MRI) due to its capabilities in multiplanar imaging and contrasting of the soft-tissue.[96] An MRI assists in measuring various characteristics associated with a tear to the RC such as determining dimensions of the tear, thickness, retraction and shape.[97] All of these characteristics can influence treatment decisions and help surgeons determine if a tear is repairable.[4] Furthermore, MRI's can also be used to assess osseous abnormalities in the presence of a RC tear which can change the route of treatment.[98] A large systematic review and meta-analysis in 2015 determined the diagnostic accuracy of

MRI's in the characterization of RC disorders.[99] Results indicated that the sensitivity for full-thickness or partial tear diagnoses ranged between 0.84-0.96, while specificity ranged between 0.84-0.95.[99] These findings help support the use of an MRI in the diagnosis of any RC tear size. In the presence of a massive RC tear or cuff tear arthropathy that constitutes surgical correction, important aspects for planning preoperative procedures include examining the severity of the RC tear, articular cartilage, and fatty infiltration of the RC muscles on an MRI.[100]

Cuff Tear Arthropathy

Cuff tear arthropathy (CTA) encompasses structural pathological characteristics of the GH joint that result from a dysfunctional RC.[101] One of the three main key physical features that characterizes CTA is superior migration of the humeral head.[4] The other two features include glenohumeral osteoarthritis and an irreparable RC.[4] CTA was initially described by these characteristics in 1983 by Neer et al.[102] He proposed that after a large RC tear, biomechanical factors within the shoulder are changed and eventually lead to degeneration of the GH joint.[102] Unbalanced forces between the dynamic stabilizers of the deltoid and RC muscles are the primary mechanical factors leading to osteoarthritic changes and superior migration associated with CTA.[4] These structural changes provide clinicians with parameters for accurate diagnosis followed by helping to make appropriate decisions for route of treatment.

Although a patient may present with these structural changes, other clinical factors should be involved in the evaluation of a patient with symptomatic CTA since multiple factors influence the assessment and management of a shoulder condition.[103]

Moreover, age, symptoms, activity level, and available shoulder motion should also be considered when attempting to influence care in this patient population.[8] Risk factors for CTA that have been reported in the literature include being a female[104], advanced age[56], high shoulder activity[105], shoulder trauma[106], and smoking[107]. Schumaier et al previously noted that it is not always clear which factors are the most critical when deciding treatment measures for CTA.[108] However, the literature has suggested that psychological and social factors are just as critical as physical measurements when deciphering treatment options.

2.2 The Biopsychological Model

The interrelationship of physical conditions and psychological factors is complex. The biopsychological model is a multidimensional approach to holistically understand a patient's health and help predict health status.[43-45,109] For example, Kroner-Herwig et al used this model to predict headaches and backpain in young adults.[43] The impetus of this model is to move away from a simple disease or biomedical model and transition towards a more comprehensive and patient-oriented approach when assessing a health condition. It is widely accepted that multiple physical and psychological avenues can influence an individual's health status. This is a more realistic model for healthcare providers to use within an orthopaedic or rehabilitation practice to contribute to the understanding and treatment of an individual's health condition.

More recently within the shoulder orthopaedic literature, there has been an emphasis placed on health-related quality of life and a patient's psychological status as these factors can influence course of treatment.[61,110-114] A psychologically informed practice in which patients are pre-surgically screened for psychological conditions is recommended by The United States Preventative Services Task Force for patients undergoing back surgery and we believe should also be recommended for patients prior to undergoing shoulder surgery.[115] Biological and psychological factors can be clinically assessed but this model has yet to be utilized as a means for better understanding the complex relationship between physical and psychological factors in patients with RC tears. It is crucial that clinicians within orthopaedic and rehabilitation practices utilize reliable, valid, and responsive patient reported outcome questionnaire's and screening tools that are meaningful to the decision-making process.

Patient Reported Outcome Measure

The patients perspective plays a crucial part during a health assessment and will greatly influence the impact of treatment.[116] Patient reported outcome (PRO) measures are used by clinicians to help assess activity limitations and participation restrictions rated by the patient.[117,118] They are also commonly used to detect short and long-term changes in symptoms and functional disability, which in turn can help improve the efficiency of treatment.[119] Healthcare providers who administer PROs allow the patient to feel more involved in their treatment since the perspectives of their function are being recorded as an interest to the provider.[120] The importance of using reliable and valid self-assessment outcome measures has continued to increase as greater emphasis is placed on patient satisfaction and quality of life outcomes after surgical interventions.[121]

Objective measures of range of motion (ROM) and strength are traditionally used to determine the impact of a shoulder condition on functional capacities but more research is supporting the use of PROs as an outcome measure that is more relevant and reflective of a patients functional capacity.[122] A study by Harreld et al in patients undergoing shoulder arthroplasty assessed objective and subjective clinical measures and found little correlation with how a patient perceives their function and how they objectively perform when measuring ROM and strength.[53] Since structural integrity of the RC and a patient's physical presentation have been shown to not always correlate, it is imperative to assess the patients subjective experience using a PRO.[123] In patients with a RC condition it is important that the outcome measure includes shoulder-specific questions. Efforts were made early on by the Research Committee of the American Shoulder and Elbow Surgeons to standardized measures of patient reported shoulder outcomes through the development of the American Shoulder and Elbow Surgeon (ASES) assessment form in 1993.[50,124]

The American Shoulder and Elbow Surgeon form

The ASES is reliable, valid and responsive in patients with RC tears.[49] The popular use of ASES is further supported by previous literature that investigated the use of the ASES and reported it as one of the most frequently utilized scoring systems for the shoulder in North America and Europe.[117] The ASES assesses patient-rated shoulder pain and function in which the higher the score, the more functional the patient is said to be.[125] Psychometric properties of this assessment form are imperative to recognize prior to use. For example, the test-retest reliability of the ASES was assessed and found to be good with an ICC of 0.94, placing confidence in using the questionnaire overtime.[49] For patients with RC conditions, the ASES has acceptable internal consistency (0.64), construct validity ($p < 0.05$), acceptable responsiveness to change (1.16), and acceptable floor (0%) and ceiling effects (0%).[49] Furthermore, appropriate criterion validity ($p < 0.05$) between the total ASES score and the physical functioning, role-physical, and bodily pain domains of the Short Form-12 scale have been determined.[49]

The form can be administered within 5 minutes and consists of two main subscales of the total score that are able to be scored separately: 1) Pain and 2) Function.[125,126] Pain is scored by a visual analogue scale (VAS) ranging from 0 (no pain at all) to 100 (pain as bad as it can be).[126] The second subscale is an assessment of reported function which asks a list of 10 questions pertaining to common daily activities. These questions are rated on a 4-point Likert scale from 0-3 by the patient based on their ability to complete the activities. A 0 indicates an inability to do the activity, reporting a 1 indicates that the activity is very difficult to perform, a 2 is indicative of the activity being somewhat difficult, and a 3 represents no difficulty in the ability to do the activity.[126] The 10 functional questions include: 1) Put on a coat, 2) Sleep on your painful or affected side, 3) Wash back/do up bra in back, 4) Manage toileting, 5) Comb hair, 6) Reach a high shelf, 7) Lift 10 lbs above shoulder, 8) Throw a ball overhead, 9) Do usual work, and 10) Do usual sport.[126]

The total score of the ASES consists of adding both the pain and function subscale together with a maximum total score of 100.[126] Each subscale is calculated to be weighted at 50% of the total score.[126] The pain subscale is scored by dividing the patients score by 2 and then subtracting that number from 50.[126] For example, a patient who reports a 100 on the VAS scale would receive a 0 after calculating the pain score, denoting the highest level of pain. The final pain score will equal a score between 0-50.

The function subscale is scored by adding each of the 10 functional questions relating to the ability to complete an activity and multiplying the score by 5/3rds.[126] The final functional score will equal a score between 0-50.[126] For example, a patient who reports a 0 (inability to do activity) on all 10 questions would receive an overall score of 0, indicating complete functional disability.

The ASES score is used frequently with surgical patients, including those who are undergoing a shoulder arthroplasty, to determine changes in pain and functional outcomes.[117,127-130] A study by Wong et al used the pain and function subscales of the ASES preoperatively to predict outcomes after shoulder arthroplasty.[131] The authors determined that patients who reported lower preoperative pain and function scores were more likely to have larger changes in their ASES outcome scores postoperatively.[131] In 67 patients with RC tears, Piitulainen et al observed wide variations in ASES scores ranging between 12-82.[112] These patients age ranged between 41-61 years old (average 54) and 57% were male. When the shoulder is functionally disabled, such as with a symptomatic RC tear, it is known that physical aspects may not be the only factors affected but also mental and social aspects. This may contribute to the wide range in reporting of ASES outcome scores and is important that physicians are aware of the multiple influencing factors in patients with RC tears. Future studies need to focus on determining these relationships and comprehensively characterizing patients who report low function versus higher function to optimize treatment outcomes.[112]

Ferreira Neto et al found that CTA negatively effects pain and function when assessed by the ASES.[76] This is currently the only study to cross-sectionally compare quality of life (QOL) (SF-12), function (ASES), and pain (VAS) in patients with CTA and recruit age- and sex-matched asymptomatic participants for comparison. These authors found significant differences between groups in pain ($p < 0.001$), ASES function ($p < 0.001$), and QOL ($p < 0.001$). But interestingly, the study did not find significant differences in mental health scores assessed by the SF-12 mental component score ($p = 0.109$). The authors suggest the non-significance observed in mental status may be the result of the complex and individualized nature of psychological distress. A debilitating disease such as CTA is more likely to negatively affect shoulder pain and function but psychological distress may be characterized more by an individual's life experiences. The authors did not attempt to correlate mental status scores with pain, function, or QOL which may could be used to help determine if this relationship exists in patients diagnosed with CTA. Understanding how these factors relate will begin to explain how they can affect one another.

The Experience of Pain

Pain is a subjective experience and although it is related to physical processes, individuals react to pain in various ways which is shaped by a host of psychological factors related to their experiences.[54] For example, there is evidence that suggests anxiety can alter pain thresholds thus predisposing a patient to experiencing pain more often.[132,133] Since chronic pain itself can cause or intensify anxiety, a perpetual cycle begins, which can significantly impact the course and management of chronic conditions such as shoulder osteoarthritis or CTA.[132] Moreover, pain acceptance has been suggested to play a crucial role in how patients cope with chronic pain.[134]

In a cohort of 393 subjects with an atraumatic full-thickness RC tear, Dunn et al found that the amount of tendon retraction, tendons involved, and fatty infiltration of the supraspinatus were not associated with pain.[55] This study shows that pain does not necessarily correlate with the severity of tissue damage. Moreover, Wylie et al examined mental health, pain, and function in patients with full-thickness RC tears and concluded that mental health has a stronger association with pain and function than the RC tear itself.[135] A qualitative study analyzed the knowledge of general practitioners on psychological and social factors and found that general practitioners often miss detecting anxiety, depression and social factors in patients with shoulder conditions, such as osteoarthrtitis.[136]

Thus, understanding the role of psychological distress, pain coping behaviors, and other psychosocial factors on patient pain and symptoms both prior to and following shoulder surgery is critical for orthopaedic surgeons during their clinical evaluation in order to optimize patient outcomes. There is a need for research to design comprehensive studies that include physical measures, psychological distress and pain in patients with common shoulder conditions such as RC tears. Capturing and evaluating these relationships will provide better understandings of patient outcomes and benefit future clinical practice guidelines.

Psychological Effects of Chronic Shoulder Pain

The ability to appropriately screen patients and recognize specific psychological constructs will allow orthopaedic and rehabilitation healthcare professionals to better refer and manage chronic pain conditions in the shoulder. Healthcare professionals who treat patients with shoulder pain need to have a thorough understanding of common psychological impairments associated with musculoskeletal related shoulder pain, especially when considering surgical versus conservative treatment options. Chronic orthopaedic conditions such as, GHOA or cuff tear arthropathy (CTA), are highly debilitating and can impact the overall well-being of an individual due to the degenerative nature of the pathology.[66,137-139] It has been reported that patients perceive the impact of shoulder osteoarthritis as comparable with systemic chronic medical conditions such as diabetes, myocardial infarctions and heart failure.[140] A phenomenological study found that symptomatic RC tears had negative impacts on patients reported emotional, work, and social quality of life.[42] Placing an emphasis on imaging and diagnosis alone may do little to address the prevention of persistent and progressive shoulder conditions.[136] In a cohort of 393 patients diagnosed with an atraumatic rotator cuff tear, painful symptoms were not correlated with RC tear size.[55] This highly suggests that there is a need for orthopaedic clinical practice to embrace broader principles other than physical attributes alone. As increasing evidence in the orthopaedic literature finds that disability correlates more with psychological factors, there is an increase interest in clinically measuring psychological correlates preoperatively to determine if there are risk factors for poor postoperative outcomes.[112]

2.3 Psychological Constructs in Orthopaedics

The Optimal Screening for Prediction of Referral and Outcomes Yellow-Flag (OSPRO-YF) assessment tool was developed as a systematic way for clinicians to identify 11 common pain-related psychological constructs in patients with symptomatic musculoskeletal conditions.[63] Psychological constructs are screened and identified as yellow flags. The literature describes yellow flags as psychological risk factors associated with disability.[63,141-145] The OSPRO-YF informs treatment making decisions and can guide treatment monitoring for patients determined to be at high risk for poor outcomes. The ability to comprehensively screen patients by including specific psychological constructs will allow orthopaedic physicians to better refer and manage RC tear related musculoskeletal pain.[47] Furthermore, this comprehensive approach can ultimately influence an orthopaedic surgeon's decision to perform surgery. We describe the 11 psychological constructs of the OSPRO-YF and reviewed the literature to determine which psychological constructs are currently the most discriminant of patient outcomes 6 months to 2-years after surgery for those with a preoperative diagnosis of a RC related condition.

Optimal Screening for Prediction of Referral and Outcomes – Yellow Flag

The OSPRO-YF assessment tool has been validated in a cohort of patients with musculoskeletal conditions and comprises of 17 questions that allows for accurate prediction of 11 different psychological constructs spanning across 3 psychological domains which include 1) negative mood, 2) fear avoidance, and 3) positive affect/coping.[64] The 17 questions provide 85% accuracy for assessing the 11 psychological constructs generated through an itemized reduction of 136 questions from 10 different validated questionnaires. These questionnaires include the 1) Patient Health Questionnaire (PHQ), 2) State-Trait Anxiety Inventory (STAI), 3) State-Trait Anger Expression Inventory (STAXI), 4) Fear-Avoidance Beliefs Questionnaire for physical activity (FABQ-PA) and 5) work (FABQ-W), 6) Pain Catastrophizing Scale (PCS), 7) Tampa Scale of Kinesiophobia (TSK-11), 8) Pain Anxiety Symptoms Scale (PASS-20), 9) Pain Self-Efficacy Questionnaire (PSEQ), 10) Self-Efficacy for Rehabilitation Outcome Scale (SER), and the 11) Chronic Pain Acceptance Questionnaire (CPAQ).[63]

Each one of these questionnaires was originally created as a result of clinical and research psychologists observing specific patient quality of life complaints relating to their chronic painful conditions. These conditions were associated with general health diseases such as cardiovascular conditions or musculoskeletal diseases. Examples of quality of life complaints include indicating fear of movement, unable to return to work due to condition or anxiety related to pain. Therefore, clinicians and researchers with a scope in psychology determined that there was a need to assess these psychological symptoms via questionnaires in patients with chronic pain condition. These psychological questionnaires have the ability to comprehensively assess potential limitations in progression of relief from symptoms. Treating clinicians will then be able to intervene on these prespecified psychological symptoms and hopefully improve quality of life. Relationships between chronic pain conditions and function have already been established in the literature but the main focus has been in the low back pain literature when it comes to the utilization of these questionnaires. The creators of the OSPRO-YF have validated their questionnaire to assess patients with musculoskeletal pain conditions in the neck, shoulder, back and legs but to date has not been examined in a surgical population.[146]

The 11 psychological constructs include 1) depression (PHQ), 2) trait anxiety (STAI), 3) anger (STAXI), 4) fear-avoidance believes for physical activity (FABQ-PA),

5) fear-avoidance believes for work (FABQ-W), 6) pain catastrophizing (PCS), 7) pain-related fear of movement (TSK-11), 8) pain-related anxiety (PASS-20), 9) pain self-efficacy (PSEQ), 10) rehabilitation self-efficacy (SER), and 11) chronic pain acceptance (CPAQ).[63] Higher scores on the PHQ, STAI, STAXI, FABQ-PA, FABQ-W, PCS, TSK-11, and PASS-20 indicate elevated symptoms related to the specific psychological construct being assessed.[63] Higher scores on the PSEQ, SER, and CPAQ are indicative of lower levels of psychological symptoms.[63] Scoring of the questionnaire may consist of 11 different numerical values indicating the existence of a yellow flag. The numeric values, established by the creators of the OSPRO-Y, specify if a patient has scored high or low enough to present with a yellow flag. Yes or no responses may also be outputted after complete numerical scoring of the OSPRO-YF. The purpose of the OSPRO-YF is not to diagnose psychological conditions such as depression, but rather to allow health care providers to screen for them. Each of the individual constructs of the OSPRO-YF are described below.

Psychological Scales of the OSPRO-YF

Patient Health Questionnaire (PHQ-9)

The PHQ-9, part of the OSPRO-YF negative mood domain, is a reliable and valid measurement tool for determining symptoms of depression.[147] Levels of depression severity are ranked minimal, mild, moderate, moderately severe, and severe depression.[147] The questionnaire consists of 9 items with a potential score ranging from 0 to 27, with higher scores indicating elevated depressive symptoms.

State-Trait Anxiety Inventory (STAI)

The STAI has two subscales, state and trait, that have been shown to accurately measure anxiety in geriatric populations.[148,149] The trait portion of the subscale was utilized in the item reduction of the OSPRO-YF to assess symptoms related to dispositional (trait) anxiety and is a part of the negative mood domain.[63] Trait anxiety refers to a steady tendency in responding to environmental stimulus as threatening.[150] This is in contrast to state anxiety where there is a transitory emotional state consisting of apprehension and nervousness. The higher the trait anxiety, the more likely an individual will experience increased elevations in state anxiety during a threatening situation which is why it is important to assess trait anxiety.[148] The trait portion of the STAI consists of 20 items with a potential score ranging from 20 to 80, with higher scores indicating elevated anxiety levels.[150]

State-Trait Anger Expression Inventory (STAXI)

The STAXI contains two subscales, state and trait, in which the trait portion was utilized in the item reduction to assess symptoms related to dispositional anger.[151] The STAXI is included in the OSPRO-YF negative mood domain.[63] This questionnaire is commonly used in anger management programs and has been shown to be reliable in the assessment of self-reported anger experience and expression.[151,152] The trait portion of the STAXI consists of 10 items with a potential score ranging from 10 to 40, with higher scores indicating elevated levels of anger.[63]

Fear-Avoidance Beliefs Questionnaire for physical activity (FABQ-PA) and work (FABQ-W)

The Fear-Avoidance Beliefs Questionnaire (FABQ) consists of the FABQ-PA and FABQ-W portions which were separate constructs during the development of the OSPRO-YF and were both part of the fear avoidance domain.[63] The FABQ was created by Waddell et al in 1993 to clinically assesses fear-avoidance beliefs about physical activity and work specific to low back pain.[153] The literature highly supports the idea that fear-avoidance beliefs may be a powerful psychological factor in chronic pain thus inspiring the development of the FABQ for routine clinical use.[153] The FABQ-PA consists of 4 items with a possible score ranging from 0 to 24 while the FABQ-W consists of 7 items with a potential score ranging from 0 to 42.[63] Higher scores indicate increased levels of fear-avoidance beliefs for both subscales. The FABQ was modified by the creator of the OSPRO-YF to assess patients with neck, shoulder, and knee conditions by replacing the word back with the desired body region.[63] Good correlations were found between the FABQ and painful anatomic regions during the OSPRO-YF validation study.[63]

Pain Catastrophizing Scale (PCS)

The PCS is a part of the OSPRO-YF fear avoidance domain and assesses the amount of exaggerated negative thoughts toward an actual or anticipated pain experience along with catastrophic thoughts related to musculoskeletal pain.[154] Pain catastrophizing has been shown to correlate with worse treatment responses in patients with chronic pain conditions providing good prognostic value.[154] The PCS has been validated and consists of 13 items with a possible score ranging between 0 to 52.[154] Higher scores indicate increased levels of pain catastrophizing.[63]

Tampa Scale of Kinesiophobia (TSK-11)

The TSK-11 assesses the degree of fear of movement and injury or reinjury and is a part of the OSPRO-YF fear avoidance domain.[63] Kinesiophobia, excessive fear of movement resulting from feeling vulnerable to a painful injury, has been identified as an important component of chronic pain due to associations with depression and anxiety.[155] The TSK is most commonly used to determine changes in fear of movement throughout patient care and after a fear-based intervention.[155,156] The questionnaire consists of 11 items with a potential score ranging from 11 to 44.[156] Higher scores indicate greater fear of movement and injury or reinjury due to pain.[63]

Pain Anxiety Symptoms Scale (PASS-20)

The PASS-20 is a reliable and valid assessment tool for determining pain-related anxiety in patients with chronic pain and is a part of the OSPRO-YF fear avoidance domain.[63] The psychometric properties of the PASS and its clinical utility have been well established to predict pain and anxiety contribution to physical function.[157] Research has demonstrated that a decrease in pain-related anxiety predicts an improvement in treatment in patients with low back pain.[158] Furthermore, research in anxiety disorders have shown that avoiding fearful physical situations may lead to maintaining anxiety as a result of disuse patterns.[158] The PASS-20 consists of 20 items, with a possible score ranging from 0 to 100. Higher scores indicate increased symptoms of pain-related anxiety.[158]

Pain Self-Efficacy Questionnaire (PSEQ)

The PSEQ assesses the degree of self-efficacy beliefs in the context of pain and is a part of the OSPRO-YF positive affect/coping domain.[63] Self-efficacy beliefs can be measured in patients through scales that determine how much effort an individual will expend and how long they will persist in the face of obstacles and adversities.[159] The self-efficacy literature supports these beliefs as aspects in explaining chronic pain experiences.[160] High PSEQ scores after pain management programs are strongly correlated with significant functional gains in chronic upper-limb pain patients.[161] The PSEQ consists of 10 items, with a potential score ranging from 0 to 60. Higher scores are desirous and indicate higher levels of pain-related self-efficacy.[63]

Self-Efficacy for Rehabilitation Outcome Scale (SER)

The SER assesses self-efficacy associated with performing tasks during physical rehabilitation and is a part of the OSPRO-YF positive affect/coping domain.[63] Self-efficacy will allow a patient to organize and execute the course of the action needed to make improvements in their disability.[162] The questionnaire increases in functional difficulty scenarios by initially assessing simple rehabilitation tasks, such as stretching, and then assessing more difficult tasks such as the ability to walk.[163] The SER consists of 12 items, scores range between 0 to 120, with higher scores indicating increased levels of self-efficacy during rehabilitation.[63]

Chronic Pain Acceptance Questionnaire (CPAQ)

The CPAQ assesses the amount of pain acceptance from a functional perspective with a focus on behavioral aspects of coping with pain.[63,164] This questionnaire is a part of the OSPRO-YF positive affect/coping domain.[63] Researchers interested in the CPAQ have previously shown that patients who have higher levels in acceptance of pain are more likely to adapt and respond better to pain beyond the influence of pain-related anxiety and depression.[165] The CPAQ consists of 20 items, with a total score potentially ranging from 0 to 120. Higher scores indicating an increased level of pain acceptance.[134]

Evidence Related to Psychological Constructs and Clinical Outcomes

A review of the literature was completed using published manuscripts that examined baseline psychological factors as predictors of outcomes in patients with RC related conditions`. Relationships between psychological factors and functional outcomes were assessed after 6-months to 2-years post-surgical intervention. Only studies in which preoperative psychological measures and postoperative outcomes were clearly defined within the text were included in this review. Since patient outcomes are inherently influenced by multiple interactions, a multifactorial approach needs to be appreciated during the design of each study. When analyzing results of a study, the use of a multivariate statistical model is most appropriate for prediction. Therefore, studies that did not include a multivariate regression model were excluded in our descriptive analysis. An outline of the six studies in which previously mentioned conditions were met are found in Table 2.1.

Table 2.1 Study Characteristics

Citation	Level of Evidence	Number of Subjects	Average Age	Preoperative Diagnosis	Operative Intervention
Potter et al. 2015[52]	Level 2 Prospective	70	61 ±2	Full thickness RC tear	Arthroscopic RC repair
Matsen et al. 2016[60]	Level 2 Prospective	337	64 ±12	GHOA; CTA; capsulorrhaphy arthropathy; AVN; posttraumatic arthritis; chondrolysis; secondary OA; RA	Hemiarthroplasty; CTA arthroplasty; Ream and run arthroplasty; TSA
Koorevaar et al. 2016[58]	Level 2 Prospective	315	52 ±16	Subacromial pain syndrome; RC tear; Instability; AC-OA; GHOA	Surgery not specifically reported
Woollard et al. 2017[57]	Level 2 Prospective	46	46 ±10	Indicated for ASD without supraspinatus repair or supraspinatus tears < 2 cm	ASD; ASD plus arthroscopic repair of a small RC tear; ASD plus repair of a small RC tear and a labral repair or biceps tenodesis; ASD plus a labral repair
Mahony et al. 2018[62]	Level 2 Prospective	441	67 ±9	GHOA; RC tear	TSA
Thorpe et al. 2018[51]	Level 2 Prospective	124	Median = 54 (range, 21-79)	Partial and full thickness RC tear	RC repair

TSA, Total Shoulder Arthroplasty; *RC*, rotator cuff; *GHOA*, glenohumeral osteoarthritis; *CTA*, cuff tear arthropathy; *AVN*, avascular necrosis; *RA*, Rheumatoid arthritis; *AC-OA*, acromioclavicular osteoarthritis; *ASD*, Arthroscopic subacromial decompression

Psychological Constructs and Outcomes in Shoulder Surgeries

The overall goal of health care providers is to improve patient outcomes. To date, research focusing on post-surgical outcomes based on psychological pre-surgical assessment has yielded mixed results as to whether psychosocial factors are predictive of outcomes for patients following surgical intervention. Matsen et al examined the Short Form-36 mental component score (SF-36 MCS) and self-report of anxiety/depression in a diagnostically heterogenous group of 337 patients who underwent surgery for shoulder conditions consisting of glenohumeral osteoarthritis (GH-OA), CTA, secondary OA, rheumatoid arthritis, or avascular necrosis.[60] The SF-36 MCS has been validated to evaluate mental health status in patients with various health conditions.[166,167] Using an appropriately powered (80%) multivariate model that included effects for patients lost to follow-up, anxiety/depression ($p = 0.124$) were not strong predictors of better 2-year postoperative outcomes assessed by the Simple Shoulder Test (SST). The SST assesses a patient's shoulder pain, function, and ability to perform activities of daily living with lower scores correlating with increased pain and decreased function.[168,169] The authors found that the SF-36 MCS scores did not significantly change from pre to postoperative ($p = 0.891$). However, better 2-year outcomes were associated with shoulder problems not related to work ($p < 0.001$), having one point lower in baseline SST score ($p < 0.001$), no prior shoulder surgeries ($p = 0.006$), no superior displacement of the humeral head on an AP radiograph ($p = 0.017$), glenoid pathoanatomy ($p < 0.001$), and having an American Society of Anesthesiologist (ASA) Class I ($p = 0.041$).[60] The ASA is a physical status classification scale that is used by anesthesiologist to indicate preoperative health that can help predict risk of surgery.[170]

In a group of 176 patients with a preoperative diagnosis of either a RC tear, GH-OA, or instability, the Four-Dimensional Symptom Questionnaire (4DSQ) was utilized to assess psychological symptoms as predictors of 1-year patient reported outcomes.[58] The 4DSQ is a validated 50-item survey for orthopaedic shoulder patients that identifies distress, depression, anxiety and somatisation.[171] Postoperative outcomes were determined by the Disabilities of the Arm, Shoulder, and Hand questionnaire (DASH), a self-report tool for upper extremity disability and symptoms.[172,173] Using a multivariate logistic analysis, powered at 80% and adjusting for age, sex, and preoperative DASH scores, the 4 psychological constructs (distress $p = 0.001$, depression $p < 0.001$, anxiety $p = 0.001$, somatization $p < 0.001$) of the 4DSQ were significant predictors of less improvement in postoperative DASH scores.[58] Interestingly, the authors noted that when accounting for postoperative scores of the 4DSQ, all significance was removed. Although most patients reported pain relief and better function after surgery, psychological symptoms did not change. Perhaps either pre- or postoperative treatment of psychological distress could lead to greater improvements in pain and function but future research would need to determine this.

A study investigating 2-year functional outcomes in 459 patients undergoing TSA for GH-OA used the Short Form-12 mental component score (SF-12 MCS) to preoperatively assess mental health status.[62] An appropriately powered (80%) multivariate analysis found that mental health status at baseline failed to statistically affect ASES outcome scores.[62] Statistically significant factors determined by the multivariate logistic regression model included the presence of a RC tear ($p = 0.025$), diabetes ($p = 0.036$) and a previous shoulder surgery ($p = 0.047$) after adjusting for race, age, sex, and body mass index (BMI).[62] Furthermore, having a higher preoperative ASES score ($p < 0.001$) was associated with poor surgical outcomes. A higher preoperative ASES score being associated with poor outcomes has consistently been shown in the literature as a result of patients having a smaller window of improvement from baseline.[62,131,174] The study also determined that preoperative RC pathology negatively affected outcomes.

In a prospective cohort of 62 patients with a supraspinatus tear, the FABQ, Clinical Epidemiologic Studies Depression Scale (CES-D), and Beck Anxiety Inventory (BAI) were used to preoperatively measure fear avoidance beliefs, depression, and anxiety, respectively.[57] Postoperative outcome measurements were collected at 6-months and assessed by the Western Ontario Rotator Cuff index (WORC) and the Global Rating of Change (GROC). The WORC is an assessment tool specifically designed to evaluate patient reported function in those who have RC related conditions.[175,176] The GROC ranges from -7 to +7, with a +7 indicating a large change in functional status.[177,178] The CES-D has been validated and was designed to measure depression symptoms in the general population.[179] The BAI reliably measures mild, moderate and severe symptoms of clinical anxiety.[180,181] A univariate regression analysis was initially conducted to determine which variables had significant relationships with a successful outcome. Success was considered based off of two criteria: 1) scoring at least a 17-point improvement on the WORC score from baseline and 2) a score of at least +5 or better on the GROC. Significance was found in those with a worker's compensation case ($p = 0.03$), dominant shoulder ($p = 0.001$), internal rotation strength >76% of the non-involved arm ($p = 0.02$), and FABQ-W <25 ($p = 0.000$). When these variables were included in a final multivariate regression model, only an FABQ-W score < 25 ($p = 0.005$) and dominant shoulder ($p = 0.009$) were predictors that explained the highest variance ($R^2 = 0.66$) of 6-month postoperative outcomes.[57]

In a cohort of 70 patients with full thickness RTC tears, the Distress Risk Assessment Method (DRAM) was measured preoperatively to identify psychological distress and determine predictors of 1-year postoperative SST scores along with ASES scores.[52] The DRAM is a validated 45-item questionnaire used in orthopaedic practice that comprises of two subscales, the modified Zung (mZung) Depression scale and the Modified Somatic Perception Questionnaire (MSPQ).[182-184] Patients can be identified as either normal, at risk, or distressed for levels of depression and somatic symptoms.[185] After conducting a multivariate analysis, powered at 80%, the mZung ($p = 0.262$) and MSPQ ($p = 0.0645$) were not predictors of differences in 1-year SST or ASES outcome scores. The authors dichotomized the patients using the DRAM into normal and distressed groups and did not find statistically significant differences in age ($p = 0.315$), gender ($p = 0.289$), size of RC tear ($p = 0.942$), RC retraction ($p = 0.68$), ASA Classification ($p = 0.359$), or BMI ($p = 0.593$) between groups.[52] The results suggest that increased psychological distress preoperatively may not necessarily be a precursor for a lack of postoperative improvements in pain and function.

Patients with a partial or full thickness RC tear were prospectively followed 1-year after a RC repair and were asked to complete the PSEQ, PCS, TSK-11, and Depression, Anxiety, and Stress Scale (DASS) psychological assessment forms.[51] The DASS is a 42-item validated questionnaire for measuring depression anxiety, and stress.[186,187] Of the 124 patients examined in this longitudinal study, 84 were distinctly clustered into a group who had good psychological functioning and 40 with poor psychological functioning defined using the median of each psychological form. Although those with lower baseline psychological function were more likely to report lower postoperative scores on the ASES, individuals who scored higher on all 4 psychological scales did not show significant differences (p = 0.984) in ASES minimal clinical important difference (MCID) scores at 1-year when compared to the lower psychological function group.[51] A multivariate model determined that women (p = 0.01) and workers compensation patients (p = 0.014) were greater predictors of worse pain and function while greater alcohol use (p = 0.031) and confidence in surgery (p = 0.026) were predictors of better pain and function assessed by the ASES.[51] The authors findings are consistent with what is most commonly reported in the literature for known preoperative predictors of outcomes in shoulder surgeries.

Table 2.2 succinctly outlines results from each of the previously described studies that had included the use of a multivariate regression analysis. The table reports all of the psychological constructs assessed preoperatively as predictor variables, patient reported outcome measurement tools used as the dependent variable, which psychological predictors were found to be predictive of worse outcomes, other clinically significant independents predictors reported, and the average postoperative follow-up time point.

Table 2.2 Results for Psychological Predictors of Postoperative Outcomes

Citation	Preoperative Psychological Construct	Patient Reported Outcome Measure	Psychological Construct Predictive of Worse Outcomes	Other Significant Predictors	Average follow-up
Potter et al. 2015[52]	DRAM	SST; ASES	None	None	1 year
Matsen et al. 2016[60]	SF-36 MCS; Self-reported anxiety and/or depression	SST	None	ASA Class; shoulder problem related to work; SST; Prior shoulder surgery; Humeral head displacement; Glenoid type	2 years
Koorevaar et al. 2016[58]	4DSQ	DASH	Depression; Anxiety; Distress; Somatization	None	1 year
Woollard et al. 2017[57]	FABQ; CES-D; BAI	WORC; GROC	FABQ-W	Dominant shoulder; WC; IR strength >76% of NI arm	6 months
Mahony et al. 2018[62]	SF-12 MCS	ASES	None	Previous shoulder surgery; RC tear; Diabetes; preoperative ASES score	2 years
Thorpe et al. 2018[51]	PSEQ; PCS; TSK; DASS	ASES	None	Women; WC	1 year

***DRAM*, Distress and Risk Assessment Method; *ASES*, American Shoulder and Elbow Surgeons; *ASA*, American Society of Anesthesiologists; *4DSQ*, Four-Dimensional Symptom Questionnaire; *DASH*, Disabilities of the Arm, Shoulder, and Hand; *FABQ*, Fear Avoidance Belief Questionnaire; *CES-D*, Clinical Epidemiologic Studies Depression Scale; *BAI*, Beck Anxiety Inventory; *WORC*, Western Ontario Rotator Cuff index; *GROC*, Global rating of change; *FABQ-W*, Fear Avoidance Belief Questionnaire-Work; *SF-12 MCS*, Short Form-12 Mental Component Score; *RC*, Rotator cuff; *PSEQ*, Pain self-efficacy; *PCS*, Pain catastrophizing; *TSK*, Tampa Scale of Kinesiophobia; *DASS*, Depression, anxiety, and stress scale; *IR*, Internal Rotation; *NI*, Non-involved; *WC*, Workers compensation**

Summary

The literature reveals that currently assessed preoperative psychological factors are not all found to be strong predictors of postoperative patient reported outcomes in this patient population. Depression, anxiety, and FABQ-W were the only baseline predictors of poor functional outcomes after shoulder surgery.[57,58] Comparable to these findings, a recent systematic review sought to determine if psychosocial factors are associated with patient-reported outcomes after treatment of a RC tear and concluded that pain and function are associated with mental health but not with postoperative patient reported outcomes.[188] Previous studies have found that preoperative education about surgery, preparation for postoperative situations, and pain neuroscience education in individuals with chronic musculoskeletal pain are effective in improving postoperative outcomes and reducing the need for postoperative analgesics and suggest that preoperative expectations could be more telling than psychological distress.[78,188-190] However, in contrast, Rauck et al evaluated patients undergoing Reverse Shoulder Arthroplasty for CTA, GHOA, or post-traumatic arthritis and did not find an association between preoperative expectations and 2-year ASES scores using a multivariate analysis.[191] There is a need for clinical research to be more comprehensive in preoperative psychological assessment to truly determine if psychological distress plays a role in postoperative outcomes.

It is possible that the psychological instruments used currently in the literature may not be capturing all psychological constructs involved in patients with chronic shoulder conditions.[171] The OSPRO-YF is comprehensive in that it captures both negative and positive psychological components such as depression and self-efficacy without questionnaire burden.[146] Furthermore, the 11 subscales of the OSPRO-YF are meaningful in that they can allow for individual tailoring of treatments. A common inference stated about psychological constructs not being predictors of outcomes was that patients with psychological disorders should not be discouraged or excluded from undergoing shoulder surgery.[52,58,192] These inferences should be interpreted with caution and questioned as to whether the results we are observing are strictly due to psychological factors not being predictors or if this is due to a lack of using measurement tools that are appropriately assessing all psychological constructs in these patient populations.

The differences in patient reported outcome measures, duration of follow-up, and rehabilitation protocols made comparing the significance in psychological predictors of outcomes very difficult. Although there was no consistency across studies with baseline psychological assessment tools utilized, the most commonly used shoulder functional outcome measure was the ASES. The use of the DASH has limitations because scores can be influenced by any other symptoms of joints in the upper extremity, not just the shoulder. Clinicians interested in assessing psychological constructs need to be certain the psychometric properties of the measurement tool are suited for their patient population. The psychological assessment tools reported in this literature review that are not included in the OSPRO-YF were the 4DSQ, BAI, SF-12 MCS, SF-36 MCS, CES-D, DRAM, and DASS. All of these questionnaires are valid measures of psychological symptoms but have been validated in different types of patient populations which may not be appropriate for patients with chronic shoulder related conditions such as CTA. This may explain why the majority of psychological assessment tools used were not strong predictors of postoperative outcomes but future longitudinal research using the OSPRO-YF is needed to determine this. Fortunately, the OSPRO-YF can be appropriately applied since it had been validated in patients with orthopaedic conditions, particularly the shoulder. A review of the literature has made it evident that it is unclear which psychological constructs are influencing patient outcomes, particularly in patients with RC related conditions.

2.4 Biomechanics of the Shoulder Complex

The primary purpose of the shoulder joint is to help position the arm in space, required by most functional tasks.[193] The shoulder complex comprises of the scapula, clavicle, and humerus. Shoulder movement requires an intricate balance between mobility and stability to achieve functional upper extremity motion.[9] During arm elevation, motion occurs at the acromioclavicular joint, sternoclavicular joint, glenohumeral joint and scapulothoracic region.[17] A bone pin study by Ludewig et al reported that during humeral elevation the clavicle will retract, elevate, and posteriorly rotate and the humerus will move in an externally rotated motion in forward flexion.[17] The authors also analyzed scapular motion and determined that during forward flexion the scapula begins to internally rotate and then at the end of humeral elevation will start to externally rotate.[17] These biomechanical studies provide clinicians with the importance and contribution of the scapula during upper extremity motion. When these structures are compromised, biomechanical faults begin to occur.[194] For example, Vidt et al found that individuals with RC tears will compensate during a functional reach task by internally rotating the humerus more throughout the task.[195] The literature provides a greater amount of data on humeral kinematics but there is still lack in the depth of understanding behind scapular kinematics, especially in a clinical setting.

Scapular Kinematics

Motion of the scapula is difficult to quantify due to the substantial amount of mobility it possesses as a result of a lack in true bony articulation with the thorax.[196] The literature has consistently described three motions and anatomical planes in which the scapula will relatively move around the thorax.[197] These include 1) upward/downward rotation in the scapular plane, 2) anterior/posterior tilt in the sagittal plane, and 3) internal/external rotation in the transverse plane.[198,199] The scapula will rotate around an axis, also described as an instantaneous center of rotation (ICR), to accomplish each one of the three motions. Biomechanical studies have found that the scapula's axis of rotation is not fixed since there is also a translational component during motion.[200-202] Since common motion trends exist around these axes, each rotation can be described in general terms. During scapular upward/downward rotation, the scapula will move around an axis perpendicular to the scapular body.[199] During scapular anterior/posterior tilt, the scapula will move around an axis parallel to the spine of the scapula.[199] During scapular internal/external rotation, the scapula will move around a vertical axis through the medial border of the scapula.[199]

Measurement Methods

Evaluation of scapular motion has gained popularity in biomechanical and clinical settings to determine the role of the scapula across many different upper extremity pathologies. To be able to comprehensively describe motion differences between shoulder pathologies, 3D biomechanical analyses are needed. These biomechanical methods include using bone pins with sensors[199], 3D motion analysis[19], electromagnetic tracking systems[203] fluoroscopic imaging, and computer modeling software[204]. Researchers have relied on these techniques to capture scapular motion to try to thoroughly understand the complex movements of the upper extremity. Although 3D biomechanical methods are some of the most accurate means of capturing scapular motion, they can be disadvantageous to a clinician interested in assessing scapular motion. Currently, clinical based studies measuring scapular motion rely on 2-D analysis or visual inspection, simplifying the complex nature of the scapula and limiting the ability to detect movement differences.[24,205-207] There is still a clinical need for an accurate and reliable measure of triplanar scapular motion. These measures are valuable to the clinical evaluation processes, treatment making decisions, and helping determine changes in motion over time without the burden of a 3D motion software system. It is well established that scapular motion plays an important role in shoulder function. Due to the current lack in the clinical ability of measuring triplanar scapular motion, health care providers are potentially missing valuable information needed for a proper plan of care. Therefore, our research team established reliability and validity of an inertial measurement unit electric goniometer to measure scapular motion. This will be described later in this section.

3D Motion Advantages and Disadvantages

In 2005, the Standardization and Terminology Committee of the International Society of Biomechanics standardized a joint coordinate systems (JCS) for each articulating segment of the upper extremity, including the scapula.[208] These 3D biomechanical testing standards yield advantages in determining precision in the position and orientation of scapular motion that cannot be accomplished using 2-D analysis.[20,209] It becomes very useful when investigating and diagnosing movement impairments of the upper extremity.[28] 3D motion analysis carries the capabilities of capturing continuous motion over time which may be useful in determining pathomechanics throughout a range of motion versus isolating start and end positions.[210] However, there are some disadvantages that must be considered when using these techniques in a clinical setting.

Disadvantages of using 3D motion analysis include the expenses associated with equipment and software, it is not easily portable, can be very time consuming, and requires an advanced skill set or years of experience to use effectively. These are not ideal features for clinical settings since it is not typical for a treating physician to be trained in the use and analysis of 3D biomechanical data associated with the application of bone pins, 3D motion cameras, electromagnetic tracking software, fluoroscopic imaging systems and computer modeling. There is also a large disadvantage in the amount of time it takes to set up a 3D motion data collection session which will pose problems to the time constraints health care providers and patients have within clinical settings. Furthermore, when it specifically comes to analyzing the upper extremity, biomechanical studies have determined that using 3D motion analysis is less reliable and valid above 120 degrees of arm elevation.[19]

Reliability and Validity of Clinical Scapular Motion

Our research team sought to determine the reliability and validity of a new clinical electrical goniometer that would allow clinicians to measure scapular mobility in all three orthogonal planes. The EasyAngle electrical goniometer (Meloq AB, Stockholm, Sweden) was used on the scapula of healthy subjects in the frontal, transverse, and sagittal planes during rest, shrug, protraction, retraction, and arm elevation to 120º on two separate days by two raters. We used an acromion marker cluster with a 14-camera motion capture system to capture scapular motion. Excursion values were extracted to calculate validity between the EasyAngle and the motion capture system using root mean square error (RMSE) and average difference (AD). Rest position and excursion values were assessed across days for intra-rater and inter-rater reliability using an intraclass correlation coefficient (ICC: (2,3)). Our results found that the RMSE values between methods ranged from 6-12º, AD ranged between -10- 4º (Table 2.3). Intra-rater reliability ICC values ranged from 0.666-0.874 (Table 2.4), and the inter-rater ICC values ranged from 0.545-0.912 (Table 2.5). The EasyAngle electrical goniometer is an accurate measure of scapular excursions in all three planes. We would like to note that the reliability of the EasyAngle is best when performed by the same rater over time following standard procedures in device placement. Future research using this device will generate more meaningful clinical information.

Table 2.3 Validity of EasyAngle against 3D Motion Analysis

Orthogonal Plane	Condition	EasyAngle Mean (SD)	3D Kinematics Mean (SD)	Avg. Diff	LOA	RMSE	Sig. *(p=0.05)*
Frontal *(Downward Rotation +)*	Shrug	-24 (7)	-26 (10)	-2	11	6	0.027
	Elev 120*	-23 (6)	-30 (7)	-7	14	10	<0.001
Transverse *(Internal Rotation +)*	Retraction	-21 (6)	-19 (7)	2	12	6	0.059
	Protraction	11 (4)	8 (7)	-3	10	7	<0.001
	Elev 120*	-8 (5)	-6 (7)	2	13	7	0.015
Sagittal *(Posterior Tilt +)*	Retraction	8 (4)	-2 (6)	-10	11	12	<0.001
	Protraction	-7 (5)	1 (6)	-1	15	11	<0.001
	Elev 120*	18 (7)	22 (7)	4	16	9	<0.001

***RMSE*, Root Mean Square Error; *LOA*, Limit of Agreement**
***Elev 120: Arm elevation to 120 degrees of flexion in the scapular plane (30° in frontal plane)**
ºAll units are in degrees with exception of significance values

Table 2.4 Intra-rater reliability of the EasyAngle

Orthogonal Plane	Condition	Mean Day 1 (SD)	Mean Day 2 (SD)	ICC	SEM	MDC_{90}
Frontal *(Downward Rotation +)*	Shrug	-20 (6)	-20 (6)	0.822	3	6
	Elev 120*	-19 (7)	-19 (6)	0.701	4	9
Transverse *(Internal Rotation +)*	Retraction	-19 (6)	-19 (6)	0.836	2	6
	Protraction	11 (4)	11 (4)	0.846	2	4
	Elev 120*	-5 (4)	-5 (3)	0.628	2	5
Sagittal *(Posterior Tilt +)*	Retraction	8 (6)	8 (5)	0.666	3	7
	Protraction	-6 (7)	-7 (6)	0.724	3	8
	Elev 120*	18 (6)	20 (6)	0.790	3	7

***SD*, Standard Deviation; *SEM*, Standard Error of Measure; *MDC_{90}*, Minimal Detectable Change at a 90% confidence interval; *LOA*, Limit of Agreement**
***Elev 120: Arm elevation to 120 degrees of flexion in the scapular plane (30° in frontal plane)**
ºAll units are in degrees with exception of ICC values

Table 2.5 Inter-rater reliability of the EasyAngle

Orthogonal Plane	Condition	Mean Day 1 (SD)	Mean Day 2 (SD)	ICC	SEM	MDC_{90}
Frontal *(Downward Rotation +)*	Shrug	-20 (6)	-20 (6)	0.822	3	6
	Elev 120*	-19 (7)	-19 (6)	0.701	4	9
Transverse *(Internal Rotation +)*	Retraction	-19 (6)	-19 (6)	0.836	2	6
	Protraction	11 (4)	11 (4)	0.846	2	4
	Elev 120*	-5 (4)	-5 (3)	0.628	2	5
Sagittal *(Posterior Tilt +)*	Retraction	8 (6)	8 (5)	0.666	3	7
	Protraction	-6 (7)	-7 (6)	0.724	3	8
	Elev 120*	18 (6)	20 (6)	0.790	3	7

***SD*, Standard Deviation; *SEM*, Standard Error of Measure; *MDC_{90}*, Minimal Detectable Change at a 90% confidence interval; *LOA*, Limit of Agreement**
***Elev 120: Arm elevation to 120 degrees of flexion in the scapular plane (30° in frontal plane)**
ºAll units are in degrees with exception of ICC values

Scapular Kinematics with a Rotator Cuff Tear

Research supports the association of abnormal scapular motion with inferior shoulder function, worse patient reported outcomes, and an increased risk for future shoulder dysfunction.[9,24,211-215] Ludewig et al reviewed several studies that examined scapular motion and its relationship with RC related conditions such as impingement symptoms or RC weakness.[196] Unfortunately, the majority of these studies did not provide diagnostic imaging to accurately determine if a RC tear was present. Furthermore, although these studies examined scapular motion during humeral elevation, the plane of elevation was not consistent across studies. Furthermore, the three scapular motions, upward/downward rotation, anterior/posterior tilt, and internal/external rotation, were not consistently assessed. There are far more fewer studies that have included 3D scapular kinematics in patients with an MRI confirmed RC tear.[,33-35,36-38,216,217] Measures of scapular kinematics within these reports are measured using either electromagnetic tracking systems (ETS) or fluoroscopic imaging. Studies comparing these two imaging techniques for measuring motion in the body found that they both demonstrate good accuracy but ETS is more advantageous in that it provides less radiation dose.[218,219] The following section will provide readers with current literature that reports on scapular kinematics in patients with a RC tear.

Upward/Downward Rotation

Scapular upward and downward rotation have been measured using 3D motion analysis in various studies. Ueda et al recruited 10 patients with a small RC tear (L x H < $5.6cm^2$), 6 with a massive tear (L x H > $5.6cm^2$), and 14 healthy controls to compare scapular motion during humeral elevation in the scapular plane.[217] Average age for the small RC tear group was 62.7 years, 64.5 years for the massive tear group, and 24.7 years for the healthy group. Motion analysis was performed using fluoroscopic movies at a rate of 5 seconds per cycle of maximal arm elevation. Scapular upward rotation differences were statistically significant ($p < 0.01$) between the massive tear group and healthy controls.[217] The massive tear group exhibited 59.8 ± 7° of scapular upward rotation at 120 degrees of humeral elevation while healthy controls exhibited 48.2 ± 4° during the same amount of humeral elevation. There were no significant differences in upward rotation between the small (57.3 ± 3°) and massive (59.8 ± 7°) RC tear groups ($p = 0.17$).[217]

Scapular kinematics were assessed between 11 patients with massive RC tears (> 5cm in two tendons) and 16 healthy controls in at study by Miura et al.[37] Average age for the massive RC tear group was 75.1 years (range, 70-86) and 71.9 years (range, 60-81) for healthy controls.[37] An electromagnetic tracking system (ETS) was used during arm elevation to 120 degrees in the scapular plane. Results determined significant differences in upward rotation ($p < 0.05$) with the massive RC group exhibiting 25 ± 9° and the healthy group 30 ± 7°.[37] Furthermore, the authors did not find any significant differences in scapular anterior/posterior tilt or internal/external rotation between the two groups.

Kolk et al examined scapular motion using an ETS in three different groups during humeral elevation to 110 degrees in the sagittal and frontal plane.[35] The groups consisted of 33 individuals with subacromial pain syndrome (SAPS), 20 with a supraspinatus tear, and 48 with a massive RC tear (> 20mm). Average age for the SAPS group was 50 ± 6 years, supraspinatus tear group was 58 ± 9 years, and massive RC tear group was 61 ± 7 years.[35] The authors only found significant differences in scapular upward rotation reporting greater upward rotation in those with a massive RC tear compared to individuals with SAPS in both the sagittal (-11 degrees [95% CI -15.0, -6.0] $p < 0.001$) and frontal (-10 degrees [95% CI [-13.2, -6.1] $p < 0.001$) planes.[35] It was also reported that patients with massive RC tears had 11 degrees more of scapular upward rotation during elevation when compared to patients with only a supraspinatus tear ($p = 0.012$).[35] Lastly, the authors reported significant differences ($p = 0.002$) between the supraspinatus tear group and SAPS group during sagittal plane elevation with the supraspinatus tear group exhibiting greater scapular upward rotation.[35] Average differences in scapular motion between groups were reported but not scapular motion excursion.

Mell et al recruited 42 subjects between the ages of 30-74 years and were placed into three groups to determine differences in scapular motion during arm elevation in the scapular and sagittal plane.[36] An ETS was used to assess scapular kinematics. The groups were as followed: 1) healthy volunteers, 2) RC tendinopathy without full-thickness examined with diagnostic imaging, and 3) RC tear > 1 cm.[2] The authors reported significant differences in scapular upward rotation ($p < 0.05$) during the mid-phase of arm elevation in the scapular plane but no significant differences at max elevation (100°) between any of the 3 groups.[36] Maximum scapular upward rotation was 24 degrees for the healthy group, 31 degrees for the tendinopathy group, and 30 degrees for the RC tear group at max elevation. P values were not reported but the authors indicated there were not significant differences between groups. Furthermore, the authors did not find any significant differences in scapular anterior/posterior tilt or internal/external rotation.

In a study by Kijima et al, the authors also did not find significant differences in upward rotation to max elevation (120°) in the scapular plane.[38] 3D scapular kinematics were examined using fluoroscopic imaging between 19 patients with either a symptomatic RC tear, asymptomatic RC tear, or a healthy shoulder.[38] Tear size was matched between asymptomatic and symptomatic groups. Average age for the symptomatic tear group was 70 (66-74) years, 67 (62-72) years for the asymptomatic tear group, and 62 (55-65) years for the healthy group.[38] An estimated calculation based off of the graph determined that scapular upward rotation for the symptomatic group was 39°, 37° for asymptomatic, and 36° for healthy. The authors did not find any statistically significant difference in scapular internal/external rotation during max elevation but did during anterior/posterior tilt, described in a later section below.

Internal/External Rotation

Scapular internal and external rotation have not been studied as in depth as scapular upward rotation but the few studies that exist can provide preliminary information as to the significant of this scapular motion in patients with RC tears. Scibek et al in 2008 examined scapular kinematics in patients with a RC tear during humeral elevation to 120 degrees using an ETS.[34] Average age for the group of patients was 60.2 ± 8.9 years. Scapular measurements were taken before and after a subacromial lidocaine injection in the sagittal, scapular, and frontal plane of elevation. The study included 8 patients with a moderate tear (1-3cm), 3 with a large tear (3-5cm), and 4 with a massive tear (>5cm).[34] Pain was assessed on a visual analogue scale ranging from 0 (no pain) to 10 (highest pain). Average pain before injection was 3.53 ± 1.99 (range, 1-8.5) and 1.23 ± 1.43 (range, 0-5) post-injection.[34] Statistically significant differences were only found in scapular external rotation during the first 40 degrees of sagittal plane arm elevation but not at maximal elevation.[34] This suggests that greater compensatory motion exists in the painful shoulder to begin elevating the arm. In 2009, Scibek et al used the same patient data to determine if scapular motion correlated with the size of the RC tear.[33] Published findings did not find any significant correlations at maximal elevation (111 ± 36°) but the authors noted that tear size negatively correlated with scapular external rotation during mid motion in all three planes of arm elevation. No other scapular motions were found to be significantly correlated with RC tear size.

Anterior/Posterior Tilt

Scapular anterior and posterior tilt has been examined the least in patients with a RC tear. Kijima et al found that the asymptomatic group with a RC tear showed similar scapular motion patterns in anterior/posterior with the healthy groups.[38] The average posterior tilt excursion value for the asymptomatic group was 9.9 ± 2.1° and 10.4 ± 0.8° for the healthy group at 120 degrees of arm elevation.[38] The symptomatic RC tear group only posteriorly tilted 3 ± 1.8° and showed statistically significant differences compared to the healthy group ($p = 0.049$) but not the asymptomatic group ($p = 0.084$).[38]

Summary

Scapular upward rotation was the most commonly measured motion. It was the most common scapular motion in which greater upward rotation existed in patients with a RC tear versus healthy individuals. The greatest difference reported was 11 degrees more scapular UR in sagittal plane elevation by Kolk et al compared to a 2-degree difference reported by Ueda et al. Studies revealed a common scapular motion trend in groups where the RC tear was more severe. In these groups the scapula tended to present with higher values of upward rotation when compared to the other groups. Authors reported maximal humeral elevation angles between 100-120°. This may make comparison of scapular motion across studies difficult since scapular motion has a direct relationship with humeral elevation. Scibek et al was the only author who reported differences in internal/external rotation but this was noted in the same group of subjects after a subacromial injection. Significant scapular anterior/posterior tilt differences were only found by Kijima et al who described these differences between patients with a symptomatic RC tear and healthy individuals. Overall, these 3D studies found that scapular motion is directly affected by RC tear size. Scapular motion differences were not exactly the same across studies. Motion varied in upward/downward rotation, internal/external rotation, and anterior/posterior tilt. These motion variations could be due to the considerable variability observed in scapular movement between individuals which also changes with plane of arm elevation, external load, speed of motion, pain, shoulder tightness, and fatigue.[220] These variables are difficult to control for and can make comparison across studies difficult. Upward/downward rotation was the measure in which there was the closest motion differences and greatest consensus in a difference existing in patients with a RC tear compared to those without. Furthermore, there is a need for health care professionals to be able to measure scapular motion clinically but currently the scapular motion literature is dominated by 3D kinematics data. Although these physical features are important to consider for functional movement, shoulder function is complex and a multitude of patient factors should also be considered within the clinical setting.

2.5 Surgical Treatment

A cuff-deficient shoulder presents challenges for orthopaedic surgeons. To avoid long-term disability due to a RC related condition such as CTA, several treatment options have been made available to the patient. It is possible to surgically leave the glenoid in place and carry out only a hemiarthroplasty but results have been shown to be somewhat disappointing and improvements in shoulder function and range of motion are still limited.[221] A Total Shoulder Arthroplasty (TSA) is another treatment option for RC conditions but a meta-analysis of 1259 patients examining the incidence of RC tears after a TSA reported that 11% had superior cuff tears and 1% underwent reoperation after TSA.[222] Several reports suggest that TSA may not be the best option for an individual with a dysfunctional RC. Currently, the most accepted surgical option for CTA is a Reverse Shoulder Arthroplasty due to its ability to surgically target each one of the key features characterizing CTA.[101]

Reverse Shoulder Arthroplasty

Paul Grammont in the 1980’s revised the reverse prosthesis, also known as a Reverse Shoulder Arthroplasty (RSA), that encompassed four key principals. These include 1) inherent stability, 2) the glenoid component must be convex and humeral component concave, 3) center of the glenosphere must be at the level of the glenoid surface, and 4) a medialized and distalized COR.[67] Grammont is still currently well-known for his principles and designs of the reverse prosthesis which has helped increase the indications for surgical implantation. The indication for undergoing a RSA has expanded over the past decade and currently includes CTA, end-stage glenohumeral osteoarthritis, pseudoparalysis, proximal humerus fractures, tumors within the proximal humerus necessitating glenohumeral reconstruction, and revision arthroplasty.[67,223] The National Inpatient Sample (NIS) in 2011 found that 80% of RSA's performed in the United States were for CTA.[224] The expansion in preoperative diagnoses has led to the increase in amount of RSA procedures performed annualy.[71,224]

The RSA was approved by the Food and Drug Administration in 2003 in the United States and has gained widespread popularity over this time period. The latest shoulder arthroplasty trends currently published is a review by the NIS database made available by the Agency for Healthcare Research and Quality between January 2011 to December 2014.[225] Palsis et al found that RSA procedures increased in the United States by 39.2% between 2011-2014 with a total of 109,724 procedures during this time.[225] The average age was 72.4 ± 8.9, 82.7% were 65 years or older, majority were female (63.8%) and white (89%). Although RSA is a relatively new approach within this population, biomechanical and clinical studies have been the center of this growing research.

Biomechanical and Functional Effects of RSA

RSA medializes the glenohumeral (GH) joints center of rotation, distalizes the humerus, and elongates the deltoid which is important for maintaining biomechanical leverage and stability.[66,226,227] This results in changes of the surrounding muscles moment arms. Moment arms are measurements of the mechanical torque exerted by the muscle around a joint and can be used to identify if a muscle is a stabilizer or a prime mover.[228] Furthermore, a muscles line of action can be used to determine whether a muscle functions as an external or internal rotator.[229] These changes are important to note since they influence the function of the shoulder muscles and thus postoperative functional outcomes. Fundamentally, the ability of a muscle to move the shoulder is a function of the moment arm and force-generating capacity.[230] Walker et al suggested that the reconstruction of the joint's geometry and muscle moment arms after RSA will improve shoulder rehabilitation.[230]

The RSA prosthesis is designed to increase the moment arm of the deltoids by moving the GH joints center of rotation inferiorly and medially.[228] Increasing the moment arm of the deltoid elongates the muscle fibers by 10-20% (20mm ±18) allowing for more muscle recruitment during shoulder elevation.[231] For reference, deltoid length is measured from the inferolateral tip of acromion to the deltoid tuberosity on the humerus.[231,232] Furthermore, this increase in muscle length reduces the deltoids required effort for torque production.[232] This reduction in torque has been recorded in cadaveric studies as high as 25% during humeral abduction.[231] However, the consequence of increasing moment arms is that there is greater demand for excursion of the deltoid for the same amount of motion after RSA.[232]

In a study by Ackland et al., RSA specifically increased the moments of the anterior and middle subregions of the deltoid, all subregions of the pectoralis major, the latissimus dorsi subregions, and the teres major.[228] The authors also found that after RSA, the moment arms of the deltoids were greatest in the coronal plane which indicates that function has greater improvement when elevating to the side in versus directly in front or in the scapular plane. Furthermore, moment arm changes resulted in the superior pectoralis major, middle deltoid, and anterior deltoid as the only subregions that were shoulder flexors. Interestingly, the superior pectoralis major subregion was the most effective flexor throughout.[228]

When examining rotator cuff moment arm changes, RSA shoulders resulted in significant ($p < 0.03$) decreases in the internal rotation moment arms of all three subscapularis subregions when compared to the anatomic shoulder.[229] The inferior infraspinatus subregion and the teres minor had the greatest external rotation moment arms after RSA but were still less than observed preoperatively.[229] The inferior subscapularis subregion had the greatest average internal rotation moment arm of all subregions. In an anatomical shoulder all of the subscapularis subregions act primarily as late adductors.[233] A cadaveric study conducted by Ackland et al measured instantaneous moment arms in RSA shoulders and found that the superior subscapularis was an abductor, while the inferior and middle subscapularis were adductors during abduction.[228] Furthermore, the teres minor rotational moment arm increased by up to 7 mm and was larger in adduction than abduction.[234] The majority of RSA studies examining moment arms of the external rotators found significant decreases in the postoperative external rotation moment arms in frontal plane elevation and sagittal plane elevation.[229,233,234]

Deltoid Effects

It has been reported that the middle and anterior deltoid go through a greater excursion between 0 to 120 degrees of abduction than in an anatomic shoulder.[229] Sabesan et al., retrospectively examined the effects of deltoid lengthening on function in patients at an average follow-up of 37 months. Outcome assessments in this study included the American Shoulder Elbow Surgeon (ASES) score, the Constant, and the

Subjective Shoulder Value (SSV).[231] Overall there were large improvements in both range of motion and functional outcome scores.[231] The authors reported a mean improvement of 76 degrees in forward elevation and 12.3 degrees in external rotation for all participants. Of those who completed the ASES, Constant, and SSV, scores were improved by an average of 44, 43, and 59 points, respectively. Although patients had significant improvements in function and outcome scores, these improvements did not specifically correlate with implant design or surgical technique. This indicates that there are multiple variables that influence outcomes. The authors also found a negative correlation between deltoid lengthening and postoperative forward elevation, suggesting that if a surgeon lengthens the deltoid too much, there may be a negative impact on functional ROM.[231] Optimal tensioning will result in increased range of motion and pain relief while excessive deltoid pre-tensioning is associated with increased risk of an acromion fracture.[231] The anterior deltoid subregion has been associated with significantly contributing to a successful clinical outcome.[235] In a cadaveric model study, researchers sought to understand the importance of the anterior deltoid for function after RSA.[236] The authors found significant decreases in flexion and abduction moments (Nm) when the anterior deltoid was unloaded, demonstrating the vital role of this muscle. Aslani et al., found that the anterior deltoid in the RSA shoulder provides more force than the anatomic shoulder at lower abduction angles in highly functioning postoperative shoulders.[237]

Biomechanical studies have found that the contribution of the posterior deltoid is significantly smaller after RSA in both extension and humeral external rotation.[229] Moreover, after RSA, the posterior deltoid subregion demonstrated a biphasic behavior during abduction. During mid to late flexion, the posterior deltoid subregion was predominantly an internal rotator, whereas in the anatomical shoulder it was an external rotator.[229] Interestingly, an EMG study found the average posterior deltoid activation did not exceed 20% MVIC during unweighted shoulder external rotation 6 months postoperative RSA.[238] This implies that the posterior deltoid may not be the main generator for shoulder external rotation. Another important observation was that deltoid activity plateaued mid-motion while UT increased linearly during greater abduction and flexion.[238]

Rotator cuff Effects

Patients with a preoperative diagnosis of cuff tear arthropathy, indicative of superior humeral head migration, retraction of the supraspinatus and infraspinatus tendons and osteoarthritis, are able to gain functional improvements after RSA.[239-241] These functional improvements in active range of motion and pain are reported to be greater when the subscapularis is reconstructed.[242,243] Edwards et al. demonstrated that an insufficient subscapularis preoperatively significantly increased the risk of postoperative dislocations.[244] Biomechanical studies have shown that it is also often possible to repair portions of the infraspinatus and teres minor.[245] It ultimately is the surgeons decision whether to preserve or release the rotator cuff muscles in these scenarios. Maier et al. showed improvements in a prospective 3D motion analysis study in the ability to comb hair, wash opposite armpit, tie an apron, and take a book from a shelf tasks after reconstruction of subscapularis.[239] Ackland et al. further supports this idea by reporting that the combined forces created by the opposing muscle lines of the subscapularis (abduction and adduction) resulted in desired compressive forces, decreasing the risk of subluxation through bracing of the humeral head against the glenoid fossa during abduction.[229] These are important factors to consider since subluxations and dislocations are one of the most common complications after RSA.[246,247] However, Boulahia et al. suggested that there may be negative consequences to subscapularis repair as it can be antagonistic against external rotation.[248]

A recent study by Dedy et al examined subscapularis tendon integrity in patients 19 months postoperative RSA.[249] The authors used sonography to determine the effect of tendon integrity on shoulder function and patient outcome.[249] Integrity grades included shoulders with intact, mildly attenuated, severely attenuated and absent tendons.[249] The authors found that tendon integrity had no measurable effects on patient reported outcomes (PROs) using Disability of Arm Shoulder and Hand, Constant-Murley, or Oxford Shoulder assessments. Statistical and clinical significant effects between tendon integrity were only found on the ability of the subject to internally rotate.[249] Although findings were not significant for PRO's, the ability to internally rotate the arm is clinically important and should be acknowledged by healthcare professionals.

Damage to the infraspinatus and the teres minor after RSA should be avoided, as these are the only major external rotators.[234] Berton et al. examined activities of daily living (ADLs) in a 3D biomechanical design and showed that RSA functional outcomes are influenced by the integrity of the external rotators, specifically the teres minor.[234] These ADLs included "reaching to the contralateral shoulder" and "drinking from a cup" which presented with greater instances of scapular notching; impingement between the humeral component and the infraglenoid aspect of the scapula. Furthermore, teres minor deficiency was associated with significantly lower postoperative Constant scores with an average score of 58 in those with teres minor deficiency versus 67 without, $p = 0.01$.[234,250] When humeral medialization was incorporated, the RC muscles were further shortened which explains postsurgical external rotation deficits and weakness.[228] Also, decreases in teres minor length, seen in lower degrees of humeral abduction, and infraglenoid impingement from a loss of muscle integrity, explains deficits seen in external rotation after RSA. Even if the teres minor external rotation moment arm is higher than in anatomical shoulders, the decreased length can impair force generating capacities when the arm is in lower degrees of abduction.[234]

Scapular Kinematic Effects

Humeral motion is frequently reported in the RSA literature while there is a paucity of knowledge on scapular motion. Research suggests that scapular involvement is an important component to evaluate since it is necessary for functional motion in an RSA shoulder.[251,252] RSA scapular motion has been quantified by various outcome variables. These variables include scapular internal rotation (IR) or lateral rotation, external rotation (ER) or medial rotation, upward rotation (UR), downward rotation (DR), anterior tilt (AT), posterior tilt (PT), retraction, protraction, elevation, and depression.[17,204] Furthermore, scapulothoracic (ST) motion has also been an outcome variable of interest and is defined as the amount of motion that the scapula moves around the thorax during arm motion.[253,254] Moreover, scapulohumeral rhythm (SHR) is an important kinematic motion that is operationally defined as the ratio determined from the kinematic interaction between the scapula (during upward rotation) and the humerus.[255] This 3D kinematic assessment method, along with other types of 3D systems, have observed differences in RSA scapular motion with 1) a change in humeral plane of motion, 2) an applied load to the arm, and 3) muscle mechanical influences.

The three main cardinal planes in which the RSA literature reports measurements of arm elevation are the sagittal, coronal or frontal, and scapular planes.[254,256] In anatomic shoulders, patterns of scapular motion change when there is a change in the cardinal plane.[17,254,257] In a 2012, Kwon et al suggested that RSA shoulders demonstrate similar scapular kinematic differences between different planes.[254] This further suggests that although shoulder kinematics may change after RSA, the scapula maintains its role in adapting to changes across shoulder cardinal planes. Furthermore, Roren et al found that the static position of the scapula tends to rest in DR after RSA when compared to healthy matched controls.[258] Reasons for these differences are currently not understood however, there is a hypothesis that it could be a compensatory mechanism of the scapula.[251] Previous RSA studies have also identified that scapular compensations can increase shear contact forces in the glenoid by 19%.[256]

Scapular UR is the most frequently reported motion in patients with an RSA. During arm elevation to 120 degrees, UR values have been recorded between 32-49 degrees in the coronal plane.[227,256] and 30-53 degrees in the sagittal plane.[255,256,259] In the scapular plane UR have been recorded around 33-55 degrees while only 20-30 degrees in healthy shoulders.[255,256,259] Studies found that UR demonstrates greater values and a relatively greater contribution during elevation when compared to healthy adults.[227,255] It should be noted that there are limitations when comparing scapular motion values across studies due to differences in measurement techniques and prosthetic designs. Moreover, Lee et al examined scapular IR and PT in subjects 2 years after RSA and did not find any significant differences during elevation in the sagittal or scapular plane.[255] Scapular IR and PT were 47 and 20 degrees in the sagittal plane and 46 and 20 degrees in the scapular plane, respectively.[255] This lack in difference needs to be analyzed in future studies to determine if these degrees of motion are normal findings in this population since the literature has not truly identified normal scapular motion after RSA.

Computation analysis of SHR to 120 degrees of arm elevation has revealed average ratios of 1.25:1 - 2.5:1 [254,255] in the sagittal plane, 1.17:1 - 2.4:1 [227,255] in the scapular plane, and 2.5:1 in the coronal plane.[254] Overall, SHR is less in all cardinal planes when compared to healthy controls.[258] Significant differences have mainly been found between RSA and healthy shoulders during rest and dynamic motion while only minimal differences between shoulders. This may be due to the fact that this patient population has major degenerative changes in both shoulders thus influencing scapular kinematics bilaterally.

SHR has also been examined during coronal plane elevation with and without a 1.4 kg hand-held weight.[260] No significant differences were observed during unweighted and weighted abduction.[260] With added load, average SHR for RSA and normal shoulders were 1.3:1 and 3.1:1 respectively. This concludes that when load is added SHR is less in RSA shoulders when compared to healthy shoulders.[260] Lower values of SHR indicates that the humerus and scapula are closer to moving concomitantly suggesting that there is greater scapulothoracic motion occurring versus glenohumeral motion.[260] Furthermore, Kwon et al examined bilateral elevation when 2lb hand weights were held in the scapular plane and found that SHR decreased significantly.[254] When load is added to the arm, RSA shoulders demonstrate lower SHR. This has functional implications because normal SHR is important for optimal scapular motion during activities of daily living (ADLs) which may require lifting weighted objects. These results can help guide rehabilitation interventions interested in strengthening periscapular muscles and should be considered as a part of rehabilitation protocols for RSA shoulders.

Biomechanical methodology was similar between studies but the authors were not completely transparent on reporting the type of RSA prosthesis utilized. This can make it difficult to compare results because function has been shown to be influenced by the type of implant design utilized.[261] Another limitation of the studies is that the control groups were not always age or sex matched. The use of the International Society of Biomechanics (ISB) standardization protocol for the upper extremity was consistently well reported. The ISB standards allow for replicability and translatability of future research. A more comprehensive understanding of the scapula's role in an RSA shoulder will guide future rehabilitation programs and determine predictors for postoperative function.

2.6 Reverse Shoulder Arthroplasty Outcomes

The effectiveness of RSA on functional outcomes continues to be researched with only limited long-term outcome studies due to its newly evolved existence as a surgical option after United States FDA approval in November of 2003.[224,262] Although the surgical procedure improves function postoperatively, inevitable mechanical and proprioceptive changes occur that reduce the chances for regaining complete functional range of motion (ROM).[263] Postoperative outcome studies of RSA for CTA have shown improvements in function and pain.[72,240,241,264] Nolan et al reported improvements in ASES scores and substantial increases in arm elevation.[241] Unfortunately, there were no improvements in shoulder external rotation but others studies have shown that this may be mainly due to the design of the implant.[265] Systematic reviews have published reporting's of long-term outcomes in patients who have undergone RSA for CTA.[72,73] These systematic reviews can help evaluate the impact of RSA on clinical outcomes.

In 2017, Petrillo et al synthesized results from 7 different studies in 408 shoulders with patients at an average age of 71.9 years. The authors found that in 228 patients who completed the ASES that pain, function and total scores were significantly different ($p < 0.05$) preoperative compared to 35.3 ± 12.3 months postoperative RSA.[73] Average preoperative ASES pain, function, and total scores were 18.1 ± 0.07, 15.7 ± 0.6, and 29.4 ± 5.2, respectively.[73] Average postoperative (35.3 ±12 months) ASES pain, function, and total scores were 40 ± 18.5, 31.8 ± 14.8, and 72.2 ± 4.1 respectively.[73] Humeral range of motion was also assessed preoperative to postoperative and statically significant differences ($p < 0.05$) were found between time-points for all humeral motions. Arm elevation preoperatively averaged at 51 ± 13.2° and 124.4 ± 11.9° postoperatively.[73] Average shoulder external rotation (ER) with the arm in adduction was 17.1 ± 6.9° preoperatively and 27.7 ±13.8° postoperatively but the authors noted that 3 of the 7 studies actually reported decreases or failures in restoring shoulder ER.[73] Similar decreases in shoulder ER findings were reported in a 2019 systematic review by Ernstbrunner et al in that 50% of the studies reviewed revealed lower shoulder ER motion postoperatively.[72] It is of major interest to health care providers to determine what clinical factors are associated with decreases in shoulder ER to improve this necessary functional movement.[266] Furthermore, a clinical device that effectively quantifies shoulder range of motion is needed to determine shoulder ER limitations. Therefore, future studies using valid clinical measurement tools are needed that are designed to help clinically determine which preoperative factors may be associated with outcomes related to poor shoulder function. Petrillo et al also reported that clinical and radiographic complications were described in all studies. Although this systematic review only assessed differences, the results show that patients diagnosed with CTA can benefit from RSA but not all patients may demonstrate clinical improvement. It is important for future studies to determine which patient characteristics are involved in those who do not demonstrate or report pain and functional improvements after RSA.

The majority of the RSA literature aims at predicting outcomes focusing on physical measures of range of motion after surgery with fewer studies placing emphasis on predicting patient reported outcomes such as the ASES.[267-270] A study by Matsen et al predicted better patient reported outcomes via the Simple Shoulder Test (SST) questionnaire 2 years after shoulder arthroplasty but this cohort included hemiarthroplasty, total arthroplasty, and reverse shoulder arthroplasty which are fundamentally different prosthesis.[60] A multivariate analysis showed 6 preoperative predictive factors for better outcomes which included the American Society of Anesthesiologist (ASA) Class I ($p = 0.041$), issue not related to work ($p < 0.001$), lower baseline SST ($p < 0.001$), no previous shoulder surgery ($p = 0.006$), no superior humeral head migration ($p = 0.017$), and other than an A1 glenoid type ($p < 0.001$).[60] This information can still be used for supporting future RSA research seeking to determine which patient factors to measure and consider preoperatively.[60] Friedman et al analyzed patient reported outcomes of 660 patients at an average age of 72 ± 8 years to determine if age and sex were associated with patient reported outcomes after RSA for CTA and revision RSA.[271] In a linear mixed effects statistical model, age was controlled which determined that men had better ASES scores than woman ($p < 0.001$).[271] When sex was controlled, every increase in age by 1-year was associated with an improvement in total ASES scores by 0.19 points ($p = 0.011$).[271] These results reveal that a relationship exists between outcomes after RSA and sex and age which will help physicians educate patients and establish expectations preoperatively.

A recent prospective study sought to predict 2-year poor patient reported outcomes after RSA in patients preoperatively diagnosed with CTA or degenerative joint disease.[272] Poor outcomes were defined as patients who reported in the lower 30th percentile of the ASES total score. A total of 137 shoulders were examine at an average follow-up time of 29 ± 8 months. Patients in the poor outcomes group averaged 64.2 points on the ASES while those with satisfactory outcomes averaged 91.3.[272] A bivariate analysis was initially used to indicate which factors were independently associated with poor outcomes and found that prior surgery on the same shoulder ($p = 0.002$) and opioid use ($p = 0.006$) were the only two factors significantly associated with poor outcomes.[272] There were no other predictors that correlated with low ASES scores such as sex ($p = 0.984$), age ($p = 0.458$), primary diagnoses ($p = 0.083$), or lower preoperative ASES scores ($p = 0.504$).[272] A multivariate logistic regression model was then used and revealed similar results. Prior shoulder surgery and preoperative opioid use were the only two associated with poor ASES scores while diagnosis, BMI, age, and ASA class were not. Although patients have significant improvements in function and outcome scores after RSA, these improvements do not specifically or singly correlate with implant design, muscle mechanics, or surgical technique. Future clinical research that examines all of the previously mentioned missing patient factors in the literature need to be conducted to better determine which patients will report better or worse outcomes after RSA.

Summary

The role of the rotator cuff (RC) has been thoroughly studied and it is well established as a dynamic stabilizer of the glenohumeral (GH) joint. The RC muscle group continuously works to neutralize forces across the highly mobile shoulder. When RC dysfunction occurs due to lesions in the tendon, pain and functional impairments become apparent. This will potentially cause further compensations in movement patterns of the upper extremity leading to greater progressions in tear size and thus more severe pathological conditions in some patients leading to CTA and due to poor control of the humerus on the glenoid will potentially lead to OA of the GH joint. Unfortunately, it has not always been clearly reported in the literature which clinical factors are the most imperative when deciding treatment for RC related disorders. Scapular kinematics have been recorded in patients with RC tears and the majority of the literature has reported that scapular motion is directly associated with RC tear size. This data suggests that as RC tear severity increases, the amount of scapular motion compensation becomes more evident when compared to healthy controls. Specifically, in the patients with RC tears, the literature finds that the scapula may not posteriorly tilt and externally rotate as much during arm elevation but this data is less consistent than reporting’s of upward rotation.

The literature supports that the scapula will significantly upwardly rotate during arm elevation in the presence of a rotator cuff tear. These compensations have been observed in each of the three planes of scapular motion during arm elevation using 3D motion software. Although 3D biomechanical data is accurate, it is not feasible to use in a clinical setting. Measuring scapular motion in a clinical setting is necessary for clinicians to be able to make appropriate treatment choices. Furthermore, the literature is overshadowed by scapular motion results only being concluded from arm elevation tasks, limiting the knowledge of other important functional motions such as shoulder external rotation.

Although physical measurements are important for predicting shoulder pain and function after treatment for RC related conditions, the literature supports that psychological factors are also predictive of outcomes. These psychological factors have specifically included depression, anxiety, and fear avoidance beliefs related to work. A disadvantage in the current knowledge of psychological factors as predictors of outcomes in patients with RC related conditions is a lack of a thorough psychological screening assessment. Moreover, psychological factors have yet to be assessed preoperative to postoperative in patients diagnosed with cuff tear arthropathy. The OSPRO-YF is a comprehensive psychological screening tool that can be used by health care providers to help identify psychological predictors of treatment outcomes that are currently still missing in the literature. This psychological screening form can be used in conjunction with the American Shoulder and Elbow Surgeons assessment form to evaluate pain and function in patients with RC tears who necessitate treatment. When surgical treatment is warranted for an irreparable RC tear and the presence of GH osteoarthritis, a Reverse

Shoulder Arthroplasty (RSA) is recommended and has been shown to provide promising functional results. There is still limited data on predictors of outcomes after RSA which may be due to it being a relatively new surgical procedure. RSA procedures have exponentially increased over the past 5-10 years and is projected to continue to increase. With RC tears being one of the most common shoulder disorders and RSA's increasing in popularity, future studies need to focus on identifying relationships between biopsychological factors and patient reported outcome measures to optimize treatment outcomes for these patients. Research continuously supports that biopsychological factors are imperative to understand within this population due to the impact they have on patient outcomes. Future clinical practice guidelines will be able to benefit from a greater understanding of these relationships. Clinical guidelines related to shoulder evaluation and treatment will begin to shift away from an isolated physical assessment method and begin to incorporate psychological screening thus helping health care providers to appropriately refer a patient for psychological care if needed. This in turn will ultimately help improve patient reported outcomes.

Chapter 3: Biopsychological Factors Associated with Worse Pain and Function in Patients with Rotator Cuff Tears

Introduction

A rotator cuff (RC) tear can negatively impact shoulder function and is associated with complaints of pain, therefore, affecting an individual's ability to perform daily activities. Rotator cuff tears may also psychologically impact an individual by shaping fear-avoidance beliefs related to physical activity (FABQ-PA).[135,188,273,274] Clinical biomechanical and psychological factors have been studied in patients with RC tears with the intent of better understanding the clinical characteristics that are representative of this patient population.[135,195,275] Psychological factors are not as commonly assessed in orthopaedic clinical settings which may be due to barriers experienced by clinicians. In a survey by Vranceaunu et al, orthopaedic surgeons stated they are "unsure how to notice, screen, discuss or refer" psychological symptoms when asked about barriers for noticing, screening, discussing, and referring patients with psychological illness in their orthopaedic practice.[276]

The orthopaedic literature describes yellow flags as psychological risk factors that can predict patient outcomes.[277] More recently there have been reports of various psychological constructs associated with outcomes in patients with musculoskeletal disabilities.[63,141-145] The Optimal Screening for Prediction of Referral and Outcomes Yellow-Flag (OSPRO-YF) assessment form was devised from 11 questionnaires addressing 3 psychological areas, negative mood, fear avoidance, and positive coping.[63] Through a regression analysis, 11 questionnaires totaling 136 items were reduced down to a 17-item questionnaire which screens for 11 musculoskeletal pain-related psychological constructs. This valid and reliable screening tool reduces patient burden of having to fill out multiple questionnaires. The OSPRO-YF is easy to administer and easily interpreted in a clinical setting. Since the psychological state of a patient may change while experiencing persistent pain and dysfunction, it is important to consider the psychological state of the patient to make better-informed treatment decisions. In the development of the OSPRO-YF patients with shoulder pain were included but a comprehensive examination of the 11 musculoskeletal pain-related psychological constructs has not been utilized in patients with MRI confirmed RC tears. Furthermore, clinically examining these psychological factors will help health care providers focus on psychological symptoms that need to be managed when establishing a course of treatment.

Biomechanical factors examined in the literature in patients with RC tears have typically focused on glenohumeral range of motion, limiting the recognition and importance of the scapula contribution to function.[123,278-282] Scapular motion is an important biological component that can change in the presence of a symptomatic RC tear when compared to healthy shoulders.[33,34,37,38,217] These documented scapular changes have been determined via 3-Dimensional (3D) motion analysis. Unfortunately, the scapula's 3D movement makes it difficult to measure in a clinical setting. The ability to measure scapular motion in a clinical setting is crucial for the advancement and execution of comprehensive clinical evaluations. Several studies have found that altered scapular motion occurs in the presence of various upper extremity conditions and may be the cause or consequence of persistent dysfunction.[9,22,214,283,284] By clinically measuring altered scapular motion, health care providers are able distinguish motion differences that may kinematically be contributing to reports of shoulder pain and dysfunction.

Patient reported pain and function are two integral elements paramount to how well an individual's quality of life is perceived.[78] It is fundamental for health care providers to determine which combination of clinical factors are influencing reports of pain and function in patients with RC tears to be able to make significant improvements and optimal treatment decisions. The American Shoulder and Elbow Surgeons (ASES) form is a standardized, valid and reliable patient reported outcome tool that is commonly used to quantify pain and function in patients with RC tears.[49] Although there is evidence to support the impact biopsychological factors can have on patient reported outcomes, the literature is still missing the identification of clinical scapular measurements and a more comprehensive psychological assessment that will help clinicians recognize which factors are associated with pain and function. More specifically, psychological constructs that have not been studied in this patient population include, pain related anxiety, anger, self-efficacy, and behavior aspects of coping with pain.

The purpose of this project was to examine the association between clinical measures of biopsychological impairments and patient reported pain, function, and total ASES scores. We tested three hypotheses: 1) the combination of decreased scapular posterior tilt during an arm flexion task and increased FABQ-PA will be significantly associated with lower ASES pain scores, indicating more pain 2) the combination of increased scapular upward rotation during an arm flexion task, decreased scapular external rotation during shoulder rotation by the side task, and increased FABQ-PA will be significantly associated with lower ASES function scores, indicating worse function 3) the combination of increased scapular upward rotation during an arm flexion task and increased FABQ-PA scores will be significantly associated with lower total ASES scores, indicating worse pain and function.

Materials and Methods

Participants

Patients were recruited from an outpatient orthopaedic clinic who were seeking medical care for shoulder pain. Participants were included if they 1) presented with shoulder pain 2) had a Magnetic Resonance Image (MRI) confirmed partial or full thickness RC tear to any one of the RC muscles, and 3) loss of active range of motion, strength or function due to a RC dysfunction. Exclusion criteria consisted of 1) previous shoulder surgery on the affected shoulder, 2) evidence of a fracture to either the humerus, glenoid, or clavicle, 3) received a subacromial injection prior to clinical testing, and 4) primary diagnosis of shoulder pain related to a condition other than a RC tear, such as cervical radiculopathy, acromioclavicular joint arthrosis, biceps tendon rupture, adhesive capsulitis, and a history of dislocation or instability causing derangement to the capsuloligament complex. The Institutional Review Board of University of Kentucky approved of this study, IRB #47739 before initiation of the study.

Procedures

Data Collection

This is a cross-sectional study design examining the associations between demographic, biological, and psychological variables with worse ASES pain, ASES function, and ASES total scores. Patients who met the inclusion and exclusion criteria were approached and consented for evaluation. The outcome variables of interest were 1) ASES pain scores, 2) ASES function scores, and 3) ASES total scores. ASES pain and function scores individually output a maximal score of 50 points which each individually represent 50% of the total 100-point ASES score.[50] A single question is asked to identify pain: "how bad is your pain today". A score of 50 on the ASES pain scale represents no pain while a 0 represents maximal pain. Ten activity questions are asked as a part of the function section. A score of 50 on the ASES function scale represents no functional limitation during the activity while a 0 represents complete dysfunction reported by the patient. All study data were collected and managed using REDCap (Research Electronic Data Capture) electronic data capture tools hosted at The University of Kentucky.[285,286] REDCap is a secure, web-based software platform designed to support data capture for research studies, providing 1) an intuitive interface for validated data capture; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for data integration and interoperability with external sources.

Demographic Variables

Demographic variables collected as independent variables included age and sex. For a thorough description of the population we also collected arm side of RC tear, mechanism of injury (atraumatic vs traumatic), height, weight, and body mass index (BMI).

Rotator Cuff Variables

RC tear size was measured in millimeters using sagittal and coronal images by an independent musculoskeletal radiologist with 7 years of experience. All MRI scans were evaluated on high-resolution digital radiology monitors at a single center using a dedicated image viewer (McKesson, San Francisco, CA, USA). The length and width of each tear were measured on the PACS to the nearest millimeter. Anterior-posterior measurements were oriented parallel to the short axis of the cuff and transverse measurements were oriented parallel to the long axis of the cuff.

Psychological Variables

The 11 psychological distress scores of the OSPRO-YF are calculated values used to indicate whether the patient is at risk for psychological distress determined by cutoff values set by the creators of the assessment form.[63] The 17-item questionnaire of the OSPRO-YF was used as it provides the highest psychological screening accuracy (85%) compared to the 10-item (81%) and 7-item (75%) portion. To calculate each score, item responses are multiplied by their associated regression weight. The following lists the psychological constructs captured using the OSPRO-YF: 1) Patient Health Questionnaire (PHQ) for depression, 2) State-Trait Anxiety Inventory (STAI) for anxiety, 3) State-Trait Anger Expression Inventory (STAXI) for anger, 4) Fear-Avoidance Beliefs Questionnaire for physical activity (FABQ-PA) and 5) fear-avoidance beliefs for work (FABQ-W), 6) Pain Catastrophizing Scale (PCS) for pain catastrophizing, 7) Tampa Scale of Kinesiophobia (TSK-11) for pain-related fear of movement, 8) Pain Anxiety Symptoms

Scale (PASS-20) for pain-related anxiety, 9) Pain Self-Efficacy Questionnaire (PSEQ) for pain self-efficacy, 10) Self-Efficacy for Rehabilitation Outcome Scale (SER), and the 11) Chronic Pain Acceptance Questionnaire (CPAQ) for acceptance of pain.[63] An in-depth explanation about the calculation of the yellow-flag numerical criteria can be found in the original paper describing the development of the OSPRO-YF.[63]

Biomechanical Variables: Range-of-Motion Analysis

Scapular and glenohumeral range of motion were measured in the clinic using an inertial measurement unit electric goniometer (EasyAngle, Meloq AB, Stockholm, Sweden). The EasyAngle has a high precision inertial measurement sensor that is accurate within 1 degree and can be calibrated in any anatomical plane to allow for clinical measurements in degrees of motion. Our previous research has established intra-rater reliability using the EasyAngle in healthy individuals described in Table 3.1. Validity of the EasyAngle has also been established against 3D motion capture (Silverson et al, in review).

Table 3.1 Intra-rater reliability of the EasyAngle

	Mean Day 1 (SD)	**Mean Day 2 (SD)**	**Lower 95%**	**Upper 95%**	**ICC**	**SEM**	**MDC90**	**LOA**
U/D_Elev 120	-19 (7)	-19 (6)	0.500	0.822	0.701	4	9	13
I/E_Elev 120	-5 (4)	-5 (3)	0.375	0.778	0.628	2	5	7
I/E_ER	-7 (4)	-7 (4)	0.702	0.903	0.830	3	6	9
A/P_Elev 120	18 (6)	20 (6)	0.642	0.876	0.790	3	7	10

***SD*, Standard Deviation; *ICC*, Intraclass Correlation Coefficient; *SEM*, Standard Error of Measure; *MDC*$_{90}$, Minimal Detectable Change at a 90% confidence interval; *LOA*, Limit of Agreement; *U/D*, Scapular upward/downward rotation; *I/E*, Scapular internal/external rotation; *A/P*, Scapular anterior/posterior tilt; *ER*, Shoulder external rotation; *Elev 120*, Arm elevation in the scapular plane to 120 degrees**

All scapular and humeral motions were measured with the patient seated in a chair flush against a wall by a single examiner. Trunk motion was carefully observed and controlled during all range of motion tasks to reduce the amount of accessory motion from the spine.

Arm Flexion Task

To evaluate the percent of scapular contribution during an arm elevation task, patients were asked to elevate their arm in the sagittal plane as high as they could without significant pain to achieve maximal elevation. Scapular motion was recorded at rest with the arm by the side of the hip and at the end position of maximal humeral elevation in the sagittal plane to complete the arm flexion task.

To record resting position of scapular anterior-posterior tilt (Figure 3.1A) the EasyAngle was calibrated to zero against the wall in a vertical position and then placed on the medial border of the scapula. The patient was then instructed to flex their arm to their maximal position in which the scapular end position was recorded (Figure 3.1B). The patient held the max position as the EasyAngle was placed on the middle aspect of the humerus to measure and record arm elevation (Figure 3.1C). To record resting position of scapular internal-external (I/E) rotation, the EasyAngle was calibrated to zero against the wall in a horizontal position and then placed on the spine of the scapula in the same position (Figure 3.2A). At the max of the arm flexion task, end position of the scapula was recorded (Figure 3.2B). The patient held the end of the arm flexion task while the EasyAngle was recalibrated to zero against the wall in a vertical position and then placed on the humerus to record arm elevation (Figure 3.2C). To record scapular upward-downward (U/D) rotation, the EasyAngle was calibrated on the floor in a horizontal position that was placed 30 degrees in the frontal plane since this is the typical angle resting position of the scapula against the spine. The EasyAngle was then placed on the spine of the scapula to record resting position (Figure 3.3A). The patient was asked to flex their arm to their maximal point in which the end position of scapular motion was recorded (Figure 3.3B). The patient held the max position as the EasyAngle was then placed on the middle aspect of the humerus to measure and record arm elevation without recalibration (Figure 3.3C). To calculate arm elevation, degrees recorded at max arm flexion position were added to 90 degrees to account for the initial calibration of the EasyAngle. The time to measure both scapular and humeral position was approximately 15 seconds so to measure all three scapular planes and humeral elevation was less than 1 minute.

Shoulder Rotation by the Side Task

During the rotation task, patients were asked to maximally rotate their adducted arm out to the side and to stop at the point of pain. To record resting scapular external rotation during this task, the EasyAngle was calibrated to zero against the wall in a horizontal position and then placed on the spine of the scapula in the same position (Figure 3.4A). At the end of the shoulder rotation by the side task, scapular end position was recorded. (Figure 3.4B). The patient held the end position while the EasyAngle was placed on the middle aspect of the forearm to measure degrees of shoulder external rotation (ER) (Figure 3.4C). The final degrees recorded were subtracted from 90 degrees due to the initial calibration of the EasyAngle. The typical reference point (0 degrees) is with the forearm facing directly forward for shoulder external rotation at the side.

Calculating Percent of Scapular Involvement

Scapular excursion was calculated by subtracted the start position from the end position. Percent of scapular involvement during each arm motion task was calculated by dividing scapular excursion by the maximum degrees of arm motion. For example, during the arm flexion task, if 30 degrees of upward rotation was measured at 110 degrees of humeral elevation, the percent of scapular involvement would be calculated by the following equation: $30° \div 110° = .27$ yielding 27%. During the shoulder rotation by the side task, scapular I/E motion was divided by the degrees of shoulder ER. For example, if 7 degrees of scapular ER was recorded during 35 degrees of shoulder ER, the percent of scapular involvement would be calculated by the following equation: $7° \div 35° = .20$ yielding 20%. Representing scapular motion as a percentage accounts for relative scapular motion suggested by Hsu et al.[287]

Figure 3.1 Scapular anterior-posterior tilt measurements during arm flexion task: (**A**) Scapular resting position. Patient is resting in scapular anterior tilt. (**B**) Scapular end position. Patient's scapula posteriorly tilted. (**C**) Arm flexion measurement

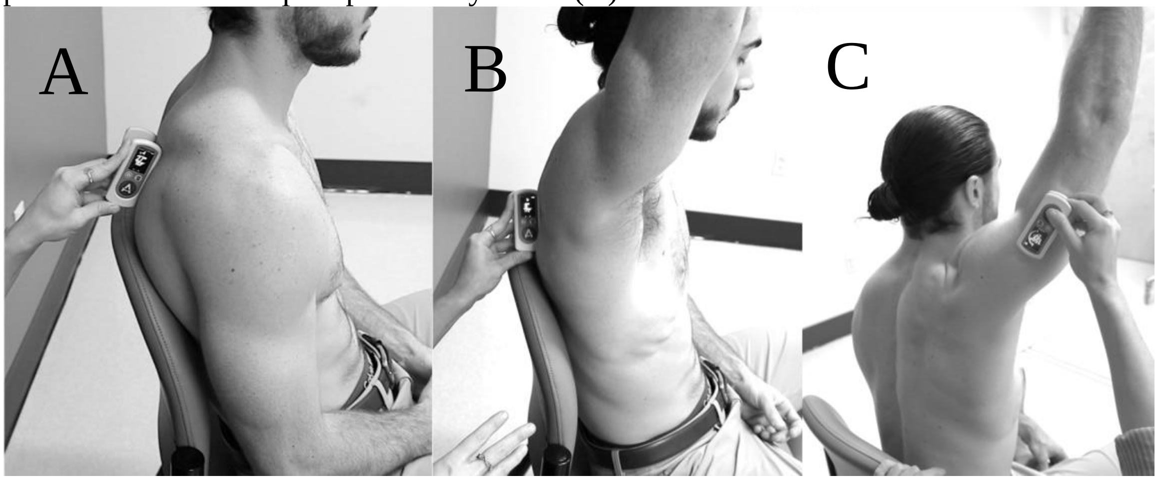


Figure 3.2 Scapular internal-external rotation measurements during arm flexion task: (**A**) Scapular resting position. Patient is resting in internal rotation. (**B**) Scapular end position. Patient's scapula externally rotated. (**C**) Arm flexion measurement

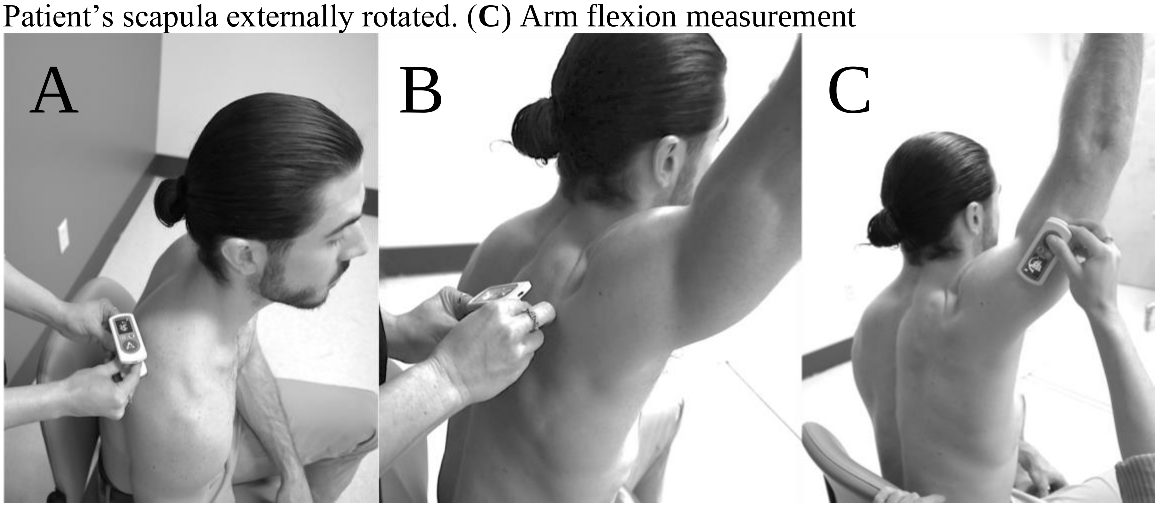


Figure 3.3 Scapular upward-downward rotation measurements during arm flexion task: (**A**) Scapular resting position. Patient is resting in scapular upward rotation. (**B**) Scapular end position. Patient's scapula upwardly rotated. (**C**) Arm flexion measurement

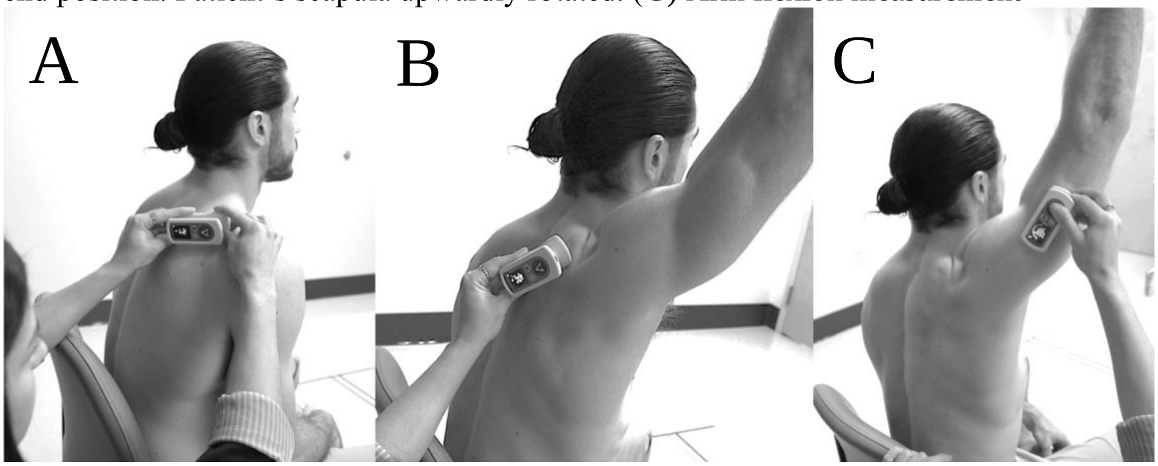
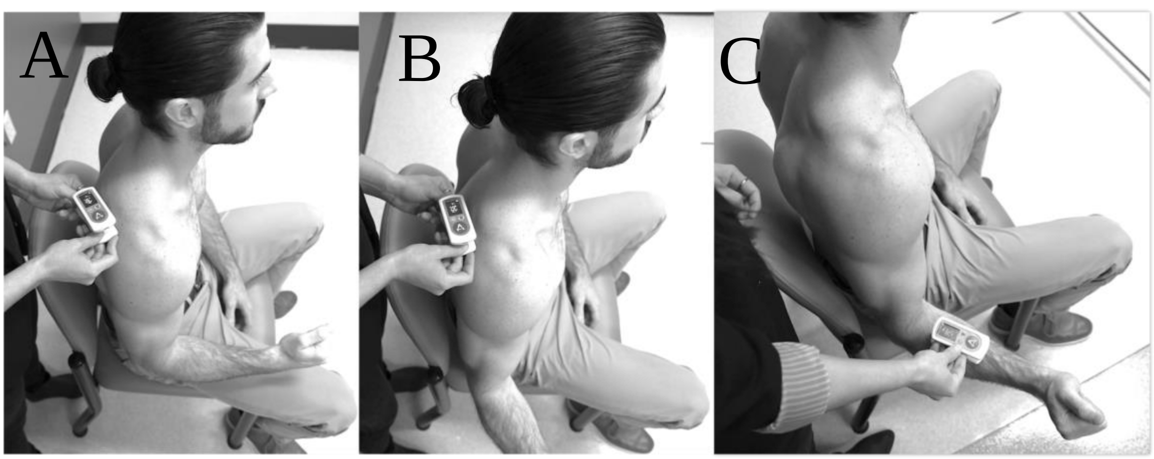


Figure 3.4 Scapular internal-external rotation measurements during shoulder rotation by the side task: (**A**) Scapular resting position. Patient is resting in scapular internal rotation. (**B**) Scapular end position. Patient's scapula externally rotated. (**C**) Shoulder external rotation measurement



Statistical Analysis

To examine the association between demographic, biological, and psychological variables with 1) ASES pain, 2) ASES function, and 3) total ASES scores a multiple linear regression with a forward stepwise approach was run. For all three dependent variables (ASES pain, ASES function, total ASES score), normality of data was confirmed by the Shapiro-Wilk test. Data values for each of the dependent and independent variables are presented as frequencies, means and standard deviations (Table 3.2) and bivariate correlations using a Pearson's correlation coefficient (Appendix A). Lastly, we checked for multicollinearity. A cutoff variance inflation factor (VIF) value of 10 was used to determine multicollinearity and variables were removed above a 10 since a VIF of 10 or above is of concern due to a high correlation represented between two independent variables can adversely affect estimations when using a regression model. All statistical analyses were performed using SPSS software version 26.0 (SPSS Inc, Chicago, IL, USA). A p value of < 0.05 was considered statistically significant.

Results

Clinical Characteristics

A total of 59 subjects were recruited and consented for the study. Nine of the subjects were excluded due to the following reasons: five of the subjects MRIs revealed tendinosis without actual tearing of the tendon, two subjects had MRIs outside of the 3-month time point, 1 subject's MRI revealed tearing at the long head of the biceps tendon, and 1 subject was not eligible due to a previous shoulder arthroscopy. Average time between date of MRI and clinical data collection was 30 ±31 days. A total of 50 subjects were included with an age range of 41 to 75 years at an average height of 1.67 meters, average weight of 91.6 ±20 kg, and an average BMI of 30 ±5. We examined 38 patients with an isolated supraspinatus tear, one with an isolated infraspinatus tear, three with a subscapularis tear, and 9 with a combined tear of the supraspinatus and infraspinatus. Anterior-posterior tear size ranged between 1.1-62mm and transverse RC tear size ranged between 1.8-42mm. There was retraction present in 30 of the 50 (60%) subjects and 38 of the 50 (76%) were atraumatic. Of the 50 subjects, 33 presented with right sided RC tears. For this sample all independent and dependent descriptive data are outlined in Table 3.2.

Table 3.2 Patient Clinical Characteristics (N = 50)

Independent variables	Data
Age, y	57 ±8
Sex	
Female	16
Male	34
Anterior-posterior tear size, mm	21.6 ±14
Transverse tear size, mm	17.9 ±13
Area of tear size, mm	521.5 ±606
Humeral elevation	117 ±39°
Shoulder external rotation	28 ±22°
% Scapular A/P	23 ±9
Posterior tilt degrees	26 ±11°
% Scapular I/E	8 ±6
External rotation degrees	10 ±9°
% Scapular U/D	27 ±10
Upward rotation degrees	31 ±12°
% TSHR	26 ±24
Scapular external rotation degrees	6 ±5°
Psychological Constructs	
OSPRO-YF score	
PHQ-9	6.1 ±4.0
STAI	36.2 ±8.5
STAXI	14.6 ±3.3
FABQ-PA	16.0 ±6.1
FABQ-W	16.8 ±11.2
PCS	18.5 ±9.1
TSK-11	26.0 ±6.0
PASS-20	37.6 ±17.5
PSEQ	34.5 ±13.7
SER	89.2 ±24.3
CPAQ	63.2 ±17.6
Dependent Variables	
Total ASES score (0-100)	52 ±20
Pain score (0-50)	27 ±12
Function score (0-50)	25 ±10

***AP*, Anterior/posterior tilt; *IE*, Internal/external rotation; *UD*, Upward/downward rotation; *TSHR*, Transverse Scapulohumeral Rhythm; *OSPRO-YF*, Optimal Screening for Prediction of Referral and Outcomes Yellow-Flag; *PHQ*, Patient Health**

Questionnaire; *STAI*, State-Trait Anxiety Inventory; *STAXI*, State-Trait Anger Expression Inventory; *FABQ-PA*, Fear-Avoidance Beliefs Questionnaire for physical activity; *FABQ-W*, Fear-Avoidance Beliefs Questionnaire for work; *PCS*, Pain Catastrophizing Scale; *TSK-11*, Tampa Scale of Kinesiophobia; *PASS-20*, Pain Anxiety Symptoms Scale; *PSEQ*, Pain Self-Efficacy Questionnaire; *SER*, Self-Efficacy for Rehabilitation Outcome Scale; *CPAQ*, Chronic Pain Acceptance Questionnaire; *ASES*, American Shoulder and Elbow Surgeon

Biopsychological Predictors

Associated Factors of ASES Pain

The multiple linear regression analysis revealed that worse ASES pain scores could be explained by two factors: decreases in percent of scapular external rotation during the arm flexion task and increased fear avoidance beliefs for physical activity (R = .62, Adjusted $R^2 = 0.364$, $p < 0.001$). The final model for ASES pain scores can be found in Table 3.3.

Associated Factors of Function

The multiple linear regression analysis revealed that worse ASES function scores could be explained by four factors: decreasing age, lower humeral elevation, lower percent of scapular external rotation during the arm flexion task, and decreases in chronic pain acceptance (R = .83, Adjusted $R^2 = 0.67$, $p = 0.003$). The final model for ASES function can be found in Table 3.4.

Associated Factors of ASES Total Scores

The multiple linear regression analysis revealed that worse ASES total scores could be explained by four factors: lower degrees of humeral elevation, lower percent of scapular upward rotation and external rotation during the arm flexion task, and increased fear avoidance beliefs for physical activity (R = .82, Adjusted $R^2 = 0.65$, $p < 0.001$). The final model for ASES total scores can be found in Table 3.5.

Table 3.3 Final multiple linear regression model for ASES Pain. (N = 50)

Variable	Constant	R	R^2	Beta	Beta CI-95 Lower Bound	Beta CI-95 Upper Bound	p-value	VIF
Model:	33.72	.624	36%					
% Scapular ER				.397	.344	1.336	0.001	1.044
FABQ-PA				-.407	-1.276	-.344	0.001	1.044

***ASES*, American Shoulder and Elbow Surgeon; *R^2*, Adjusted R Square*; R*, Regression correlation value*; VIF*, Variance inflation factor*; CI*, Confidence Interval*; ER*, External rotation; *FABQ-PA*, Fear-Avoidance Beliefs for Physical Activity**

Table 3.4 Final multiple linear regression model for ASES Function. (N = 50)

Variable	Constant	R	R^2	Beta	Beta CI-95 Lower Bound	Beta CI-95 Upper Bound	p-value	VIF
Model:	-22.18	.833	67%					
Age				.180	.014	.426	0.000	1.028
Humeral Elevation				.476	.075	.172	0.000	1.254
% Scapular ER				.191	.010	.662	0.037	1.247
CPAQ				.476	.177	.374	0.044	1.051

***ASES*, American Shoulder and Elbow Surgeon; *R^2*, Adjusted R Square*; R*, Regression correlation value*; VIF*, Variance inflation factor*; CI*, Confidence Interval*; ER*, External rotation; *CPAQ*, Chronic Pain Acceptance**

Table 3.5 Final multiple linear regression model for ASES Total. (N = 50)

Variable	Constant	R	R^2	Beta	Beta CI-95 Lower Bound	Beta CI-95 Upper Bound	p-value	VIF
Model:	38.04	.823	65%					
Humeral Elevation				.315	.060	.255	0.002	1.301
% Scapular UR				.237	.121	.798	0.009	1.052
% Scapular ER				.327	.467	1.747	0.001	1.228
FABQ-PA				-.493	-2.146	-.994	0.000	1.126

***ASES*, American Shoulder and Elbow Surgeon; *R^2*, Adjusted R Square*; R*, Regression correlation value*; VIF*, Variance inflation factor*; CI*, Confidence Interval*; UR*, Upward rotation; *ER*, External rotation; *FABQ-PA*, Fear-Avoidance Beliefs for Physical Activity**

Discussion

The principle finding of this study is that a multivariate approach examining clinical biopsychological factors in patients with RC tears is necessary to better understand clinical components leading to ASES pain, function, and total scores. The biopsychological variables selected for analysis in this study were chosen using supporting data from the literature, clinical relevance, and to bridge current research gaps. The use of a multiple regression model allows for simultaneous evaluation of the relationships between multiple clinical factors that exist in patients with RC conditions. Determining the involvement biopsychological factors have on patient reported outcomes will allow for tailored treatment decisions resulting in favorable outcomes related to pain and function. Modifiable clinical factors were identified that can be addressed during treatment plans for this patient population. Furthermore, clinical research in patients with RC tears needs to be more comprehensive in its psychological assessment to truly determine how psychological distress plays a role in outcomes. Current psychological instruments used in the literature and clinical settings may not be capturing all relevant psychological constructs. There are 11 psychological constructs assessed by the OSPRO-YF that have been validated in patients with chronic shoulder conditions.[171] A strength of our study was that we used the OSPRO-YF to comprehensively screen 11 psychological symptoms.

While physical examinations are important to conduct for treatment decisions, physical examination does not completely explain the patient's perception of shoulder pain and function. Each model included at least one biological and one psychological variable that contributed toward explaining 36% of variance in pain scores, 67% in function, and 65% in total ASES scores. Our results support using the biopsychological model as a clinical evaluative approach when seeking to improve patient self-reported outcomes. In our cohort, the combination of arm elevation, percent of scapular upward rotation, percent of scapular external rotation, and fear avoidance beliefs for physical activity predicted total ASES score. Health care providers can work toward improving patient reported outcome scores by focusing on these individual variables.

The hypotheses of our biopsychological model were supported for every component of the ASES scores even though we were not 100% correct. The results of this study partially supported our first hypothesis, as increased FABQ-PA was associated with worse ASES pain scores but decreased scapular posterior tilt during arm elevation was not. However, the study found that decreased scapular external rotation during arm elevation was associated with worse ASES pain scores. The second hypothesis was not supported. The study showed that younger age, less humeral elevation, decreased scapular external rotation during arm elevation, and a lower score on the chronic pain acceptance questionnaire were associated with lower ASES function scores. The third hypothesis was partially supported in that FABQ-PA was associated with worse total ASES scores. The study also found that less humeral elevation, decreased scapular upward rotation and decreased scapular external rotation during arm elevation were significantly associated with worse ASES total scores.

The population in this study was comparable to previous studies. Age range (41-75 years) and gender (male, 68%) characteristics of our patient population are similar to several studies, particularly those reported in a systematic review of patients with small to large traumatic RC tears.[288] Mall et al reported RC patients were on average 55 years old (range, 34 -61 years) and primarily male (77%). Friedman et al found that in patients with cuff tear arthropathy, men and older age were associated with improved American Shoulder and Elbow Surgeons (ASES) form total scores.[271] In the current study, we also found that older age was a significant demographic factor associated with higher ASES function scores. ASES pain and function were evaluated by Harris et al[289] in patients with symptomatic atraumatic full-thickness RC tears, similar to our patient population. The authors reported an average ASES total score of 53.9 ±18 which is in line with our average score of 52 ±19 but ASES pain and functions scores were not separately reported for direct comparison. Interestingly, the authors found that sex was associated with higher ASES total scores ($p = 0.001$) which does not match our results.[289] Differences in these results could have been due to the differences in gender demographics. This study recruited majority male participants while Harris et al recruited an even amount of males and females.

Several 3D motion studies in patients with RC tears have found that patients with massive RC tears typically present with greater scapular UR and less scapular ER when compared to healthy cohorts.[35,37,38,216,217] Other research examining 3D scapular motion in patients with RC related impingement found significant differences in scapular ER during arm elevation tasks when compared to healthy individuals.[290,291] These authors reported significantly less degrees of scapular ER in the pathological group.[290,291] It is worth noting that our study is the first study to associate triplanar clinical measurements of scapular motion with patient reported pain and function in individuals with RC tears. Due to the 3D nature of the scapula, capturing triplanar scapular motion is limited to conducting 3D motion analysis which is impractical in a clinical setting. Our research team used a valid and reliable measurement device to clinically assess triplanar scapular motion during arm tasks as a critical component in the physical examination process. Scapulothoracic motion is important for shoulder motion and without controlled movement, there is a higher propensity for a shoulder pathology to occur such as a RC tear.[24,214]

The use of scapular motion as a percentage is novel but appropriately represents the contribution of scapular motion to total arm elevation. As technology advances, the ability to measure both humeral and scapular motion independent in the clinic is enhanced as demonstrated in this study. Similar to our methodology, Hsu et al also examined percent of scapular involvement during arm elevation in 352 patients before elective surgery for osteoarthritis (n = 161), RC tears (n = 46), cuff tear arthropathy (n = 43), failed RC repair (n = 30), secondary degenerative joint disease (n = 23), and capsulorrhaphy arthropathy (n = 15).[287] The authors only examined scapular upward rotation and found that it contributed to 17% of arm elevation (12 ±10°) of upward rotation during 72 ±38° of arm elevation) while our results found that scapular UR contributed to approximately 27 ±10% of arm elevation (31 ±12° of upward rotation during 117 ±39° of arm elevation). Differences in their percent of scapular motion compared to ours are most likely due to the difference in degrees of arm elevation and differences in shoulder conditions. As the arm elevates, the scapula increases in the amount it upwardly rotates, therefore our larger percentages can be explained by the 45 more degrees of arm elevation in our patient population. This increase observed in scapular upward rotation is likely due to compensatory motion of the shoulder in order to achieve maximal arm elevation.

Rotator cuff tears certainly limit function but also affect a person's emotional state.[292] In patients with RC tears physical factors, such as tear size, age and family history, have been shown to predict shoulder pain.[293] However, previous studies have also found that the rotator cuff tear size had little bearing on patient's perception of pain or function.[135] The RC is a critical component of shoulder function and when this structure is significantly affected, not only does an individual's movement patterns change but their emotional state is also affected.[273] Previous studies have already determined that physical factors can be less predictive of ASES patient reported outcomes than psychosocial factors in those with RC tears.[188] Wylie et al found that mental health had a stronger association with patient reported pain and function than the size of the RC tear.[135] Dunn et al reported similar results in that pain did not correlate with RC tear severity but found that comorbidities, education, and race were the only significant associated factors.[55] A prospective study investigated predictive clinical factors of pain after RC repair and found that psychosocial factors were stronger predictors than structural factors.[294] Although the patients in the prospective study were assessed after rotator cuff repair, these results may still be translatable in understanding the relationship physical and psychological factors have on patient reported pain and function. Depression and anxiety have been the psychological focus of RC research in previous studies.[188,295] We demonstrated that fear and pain acceptance play a major role in patient reported pain and function. Unfortunately, only focusing on depression and anxiety does not allow physicians to appreciate the complexity of an individual's psychology, especially when we know that multiple psychosocial constructs can be expressed in the presence of a musculoskeletal injury.

Limitations

Study limitations should be considered with these findings. Pain medication during time of data collection was not recorded which could misrepresent pain responses, potentially changing association values. It is likely that symptomatic patients will attempt to medicate but this may not be true for all patients as not every individual responds to pain in the same way. Although our biopsychological model did not include all possible clinically relevant factors, we were able to focus on key biopsychological variables that have clinical relevance. Another limitation of this study was the lack of capturing duration of symptoms which could have helped with determining whether psychological symptoms were affected by the amount of time a patient was symptomatic for. Future studies should include a larger sample size to allow for the inclusion of our study limitations and to provide a sound statistical analysis. Additionally, future studies should conduct a prospective study design that follows patients over time, ideally, after a treatment intervention as this can provide more insight on the influence biopsychological variables have on patient report pain and function.

Conclusion

A multivariate approach examining clinical biopsychological factors in patients with RC tears is necessary to better understand clinical components leading to self-reported pain and function. The most significant combination of biological and psychological factors that influence ASES pain and function in patients with a symptomatic rotator cuff tear include age, humeral elevation, scapular external rotation during an arm flexion task, scapular upward rotation during an arm flexion task, chronic pain acceptance behaviors, and fear avoidance beliefs of physical activity. Focusing on these variables will guide health care providers in the right direction toward improving patient reported scores on the ASES. Our results favor adopting a comprehensive biopsychological model over focusing solely on the physical features during clinical examination of patients with a rotator cuff pathology.

Chapter 4: A Biopsychological Model for Predicting Worse Pain and Function After a Reverse Shoulder Arthroplasty for Cuff Tear Arthropathy

Introduction

The main indicator for undergoing a Reverse Shoulder Arthroplasty (RSA) is the loss of shoulder function as a result of unstable forces surrounding the glenohumeral joint.[226] Cuff Tear Arthropathy (CTA) is a condition in which unstable forces acting on the shoulder joint become determinantal to the integrity of the musculoskeletal tissue, necessitating an RSA.[4] The three major characteristics of CTA are the presence of 1) an irreparable cuff tear, 2) osseous degeneration, and 3) superior migration of the humeral head.[4] One of the main goals in performing an RSA is to restore as much of the original function of the glenohumeral joint while restoring as much pain free motion that can be achieved during activities of daily living (ADLs). As pain and functional outcomes are undoubtedly multifactorial, it is necessary to determine which combination of clinical factors are contributing to patient reported outcomes. A biopsychological model allows clinicians to appreciate the multifaceted nature of patient outcomes by approaching treatment that considers factors related to both physical features and psychological symptoms.

Shoulder range of motion is a physical indicator of function and is most commonly measured in isolation; however, this motion consists of a combination from the movement of the humerus and the scapula.[17,204,253] Scapular motion has been kinematically quantified in patients with RSA using 3D motion analysis to examine how scapular kinematics differ when compared to a native shoulder.[227,255,256,258,260]

Researchers have found that scapular motion differs between the contralateral shoulder of patients with an RSA and healthy individuals.[253,254] This difference includes greater scapular upward rotation degrees during arm elevation in patients with RSA. Clinically, it is unclear if scapular mobility is a predictor of patient reported outcomes after RSA; however, computer simulated models suggest that limited scapular mobility is a risk factor for postoperative prosthetic complications.[251,252] Patients suffering from CTA and who are indicated for an RSA report their quality of life is reduced due to limitations in their ADLs.[76] ADLs require scapular and humeral motion, humeral motion is commonly assessed but scapular motion is not clinically assessed but may be a key clinical factor to assess pain and function as a patient recovers from RSA.[296]

It is well known that a patient's psychological state is a potential risk factor for developing poor treatment outcomes.[47] Recent prospective studies have shown that psychological symptoms such as an inability to cope with pain and distress are significantly correlated with less improvements in pain and function scores following rotator cuff repair, scapular muscle reattachment, and total shoulder arthroplasty.[58,59,277,297-299] Furthermore, the literature has demonstrated that shoulder pain has a stronger correlation with a patient's psychological state than with the magnitude of local tissue involvement.[55,299,300] Pain-associated psychological factors can be measured using a validated psychological screening tool - the Optimal Screening for Prediction of Referral and Outcome for Yellow Flags (OSPRO-YF).[63,64] The OSPRO-YF evaluates two domains, resilience and vulnerability, of musculoskeletal pain-associated psychological distress.[63] The OSPRO-YF is a 17-item questionnaire that provides estimates of 11 psychological constructs including fear avoidance beliefs of physical activity (FABQ-PA) and chronic pain acceptance behaviors.[63,64] The OSPRO-YF assists clinicians in assessing patients psychological status that may require additional consultation than just a surgical intervention. Despite successful surgical treatment, a poor outcome may be due to under-appreciated psychological distress or lack of patient satisfaction of the result.

Previous research has demonstrated that age, sex, and scapular upward rotation are associated with outcomes after RSA.[271,301,302] Scapular motion has been shown to significantly differ in patients with RSA than healthy controls in that they present with greater degrees of scapular upward rotation.[227] Friedman et al found that men and older age were associated with improved American Shoulder and Elbow Surgeons (ASES) form total scores.[271] The success of RSA treatment is commonly measured by the ASES, a patient-reported outcome score.[127,128,130,303] Currently, the identification of pain-associated psychological distress and coping styles that predict patient-reported outcomes in patients with CTA preparing to undergo RSA has yet to be addressed. The development of a biopsychological prediction model will positively influence clinical care and allow for the development of protocols to improve postoperative pain and function.

Both altered scapular mobility and abhorrent pain coping behaviors are modifiable, but not necessarily mutually exclusive and can co-exist in this subset of patients. To address this unmet clinical need, it would be beneficial to examine the complex interplay between psychological factors and scapular and shoulder mobility on postoperative outcomes. Given the ongoing attention and importance of reducing both pain and disability in patients with CTA, research in this area is still needed. Therefore, the purpose of this study is to establish preoperative clinical biopsychological factors that may predict patients who report worse pain, function, and total scores assessed by the

ASES one-year after RSA. We will test the following hypotheses: 1) increased FABQ-PA will be most predictive of worse ASES pain scores at 1 year, 2) increased scapular upward rotation during an arm flexion task will be most predictive of worse ASES function scores at 1 year, and 3) the combination of increased scapular upward rotation during an arm flexion task and FABQ-PA will be predictive of worse total ASES scores one-year after RSA. Determining the involvement of biopsychological factors on patient reported outcomes will allow for tailored treatment decisions, leading to more optimal postoperative outcomes.

Methods

Study Population

Using a prospective study design, patients with CTA who underwent primary RSA in 2018-2019 were enrolled in an IRB-approved shoulder arthroplasty registry. The Institutional Review Board of University of Kentucky approved of this study, IRB #47739. Inclusion criteria consisted of having a preoperative diagnosis of CTA defined by the Hamada classification[304] and if the patient underwent a primary RSA. Patients were excluded if they had incomplete preoperative and 1-year postoperative data.

Procedures

Independent variables include demographics such as sex and age, the 11 psychological distress scores of the OSPRO-YF, humeral elevation, and percent of scapular upward rotation (UR) contribution during humeral elevation. All independent variables were captured preoperative and 1-year postoperatively. Since it is the patient's subjective impression of their health status that is most important to the success of treatment it was decided that the ASES assessment score at 1 year would be most appropriate to use as our outcome variable. Data collected at 1-year postoperative RSA included the ASES pain, ASES function, and ASES total scores which were calculated using the ASES assessment form. ASES pain and function scores individually output a maximal score of 50 points which each individually represent 50% of the total 100-point ASES score.[50] A single question is asked to identify pain: "how bad is your pain today". A score of 50 on the ASES pain scale represents no pain while a 0 represents maximal pain. Ten activity questions are asked as a part of the function section. A score of 50 on the ASES function scale represents no functional limitation during the activity while a 0 represents complete dysfunction reported by the patient. All study data were collected and managed using REDCap (Research Electronic Data Capture) electronic data capture tools hosted at The University of Kentucky.[285,286] REDCap is a secure, web-based software platform designed to support data capture for research studies, providing 1) an intuitive interface for validated data capture; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for data integration and interoperability with external sources.

Psychological Variables

The 11 psychological distress scores of the OSPRO-YF are calculated values used to indicate whether the patient is at risk for psychological distress determined by cutoff values set by the creators of the assessment form.[63] The 17-item questionnaire of the

OSPRO-YF was used as it provides the highest psychological screening accuracy (85%) compared to the 10-item (81%) and 7-item (75%) portion. To calculate each score, item responses are multiplied by their associated regression weight. The OSPRO-YF captured the following psychological constructs: 1) Patient Health Questionnaire (PHQ) for depression, 2) State-Trait Anxiety Inventory (STAI) for anxiety, 3) State-Trait Anger Expression Inventory (STAXI) for anger, 4) Fear-Avoidance Beliefs Questionnaire for physical activity (FABQ-PA) and 5) fear-avoidance beliefs for work (FABQ-W), 6) Pain Catastrophizing Scale (PCS) for pain catastrophizing, 7) Tampa Scale of Kinesiophobia (TSK-11) for pain-related fear of movement, 8) Pain Anxiety Symptoms Scale (PASS-20) for pain-related anxiety, 9) Pain Self-Efficacy Questionnaire (PSEQ) for pain self-efficacy, 10) Self-Efficacy for Rehabilitation Outcome Scale (SER), and the 11) Chronic Pain Acceptance Questionnaire (CPAQ) for acceptance of pain.[63] An in-depth explanation about the calculation of the yellow-flag numerical criteria used to determine psychological distress can be found in the original paper describing the development of the OSPRO-YF.[63]

Biological Variables

Scapular and humeral range of motion were measured in the clinic using an inertial measurement unit electric goniometer (EasyAngle, Meloq AB, Stockholm, Sweden). The EasyAngle has a high precision sensor that is accurate within 1 degree and can be calibrated in any anatomical plane to allow for clinical measurements in degrees of motion. Our research team established intra-rater reliability using the EasyAngle in healthy individuals described in Table 4.1. Validity of the EasyAngle has also been established against 3D motion capture (Silverson et al, unpublished data).

Table 4.1 Intra-rater reliability of the EasyAngle

	Mean Day 1 (SD)	Mean Day 2 (SD)	Lower 95%	Upper 95%	ICC	SEM	MDC90	LOA
UR_Elev 120	-19 (7)	-19 (6)	0.500	0.822	0.701	4	9	13

***SD*, Standard Deviation; *ICC*, Intraclass Correlation Coefficient; *SEM*, Standard Error of Measure; *MDC₉₀*, Minimal Detectable Change at a 90% confidence interval; *LOA*, Limit of Agreement; *UR*, Upward Rotation**

All scapular and humeral motions were measured with the patient seated in a chair flush against a wall by a single examiner. To evaluate the percent of scapular contribution during an arm elevation task, patients were asked to elevate their arm in the sagittal plane as high as they could without significant pain to achieve maximal elevation. Scapular motion was recorded at rest with the arm extended by the side of the hip and at the end position of maximal humeral elevation in the sagittal plane to complete the arm flexion task.

To record scapular UR, the EasyAngle was calibrated on the floor in a horizontal position that was placed 30 degrees in the frontal plane since this is the typical resting position of the scapula on the spine. The EasyAngle was then placed on the spine of the scapula to record resting position (Figure 4.1A). The patient was asked to flex their arm to their maximal point in which the end position of scapular motion was recorded (Figure 4.1B). The patient held the max position as the EasyAngle was placed on the middle aspect of the humerus to measure and record arm elevation (Figure 4.1C). To calculate arm elevation while recording scapular UR, degrees recorded at max arm flexion position were added to 90 degrees due to the initial calibration of the EasyAngle. If a patient presents with less than 90 degrees of arm elevation, the amount of degrees will then be subtracted from 90.

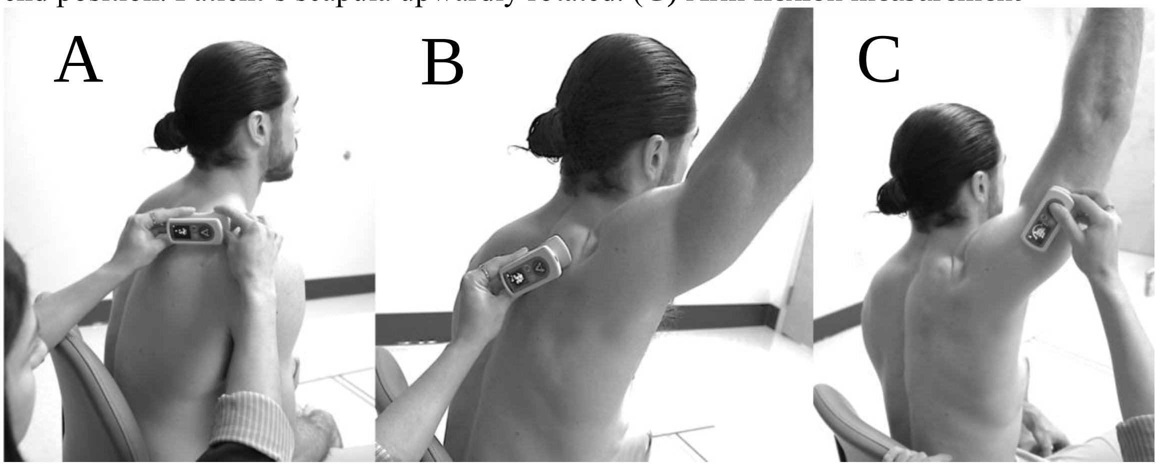
Trunk motion was carefully observed and controlled during all range of motion tasks to reduce the amount of accessory motion from the spine. Scapular excursion was calculated by subtracting the start position from the end position. Percent of scapular involvement during each arm motion task was calculated by dividing scapular excursion by degrees of arm motion. For example, if 30 degrees of upward rotation was measured during 110 degrees of humeral elevation, the percent of scapular involvement would be calculated by the following equation: 30° ÷ 110° = .27 yielding 27%. Percent of scapular motion methodology is supported by Hsu et al.[287]

Operative and Postoperative Procedures

All surgeries were performed by a single board-certified orthopaedic surgeon (C.M.H) using a surgical deltopectoral incision approach. The implant design *Aequalis Ascend™ Flex Reversed Shoulder System (*Tornier, Bloomington, MN, USA) was utilized in 14 patients and the *Comprehensive Reverse Shoulder System* (Zimmer Biomet, Warsaw, Indiana, USA) in 2 patients. Implant design followed the medialized glenosphere and lateralized humeral components technique.

All patients were instructed on the same postoperative rehabilitation protocol (Appendix B) which included a 6-week use of an abduction shoulder sling following surgery (Donjoy Ultrasling III, Vista, California), initiation of active assist shoulder flexion to 140 degrees via home exercises beginning the day after surgery (exercises taught to patient by a physical therapist). Furthermore, at 3 months patients were instructed to begin the shoulder strengthening phase of rehabilitation without restrictions on active ROM.

Figure 4.1 Scapular upward-downward rotation measurements during arm flexion task: (**A**) Scapular resting position. Patient is resting in scapular upward rotation. (**B**) Scapular end position. Patient's scapula upwardly rotated. (**C**) Arm flexion measurement



Statistical Analysis

To examine the association between demographic, biological, and psychological variables with 1) ASES pain scores, 2) ASES function scores, and 3) total ASES scores a multiple linear regression with a forward stepwise approach will be run. A p value of < 0.05 was considered statistically significant. For all three dependent variables (ASES pain, ASES function, total ASES score), normality of data was confirmed by the Shapiro-Wilk test. Data values for each of the dependent and independent variables are presented as frequencies, means and standard deviations (Table 4.2). Variables forced in the multiple linear regression model using Enter in Block 1 included, age and sex, and scapular upward rotation since they have already been shown in the literature to be associated with outcomes.[271,301,302] Lastly, we checked for multicollinearity. A cutoff variance inflation factor (VIF) value of 10 was used to determine multicollinearity and remove variables above a 10 since a VIF of 10 or above is of concern due to the high correlation represented between two independent variables which can adversely affect estimations when using a regression model. All statistical analyses were performed using SPSS software version 26.0 (SPSS Inc, Chicago, IL, USA).

Results

A total of 23 patients from the registry were eligible. Seven patients were lost to follow-up due to a lack in response to return for their 1-year follow-up appointment leaving sixteen patients at the end of follow-up. Age of patient's ranged from 54 - 83 years. Our cohort was predominantly female (12/16, 75%) with an average height of 1.74 meters, average weight of 79.8 ±16 kg, and an average BMI of 28 ±6. A greater percentage of right shoulders were affected 12/16 (75%). Average follow-up time was 390 ±81 days (range, 284 – 613).

Table 4.2 Patient Clinical Characteristics (N = 16)

Independent variables	Preop Data	Postop Data
Age, y	68 ±8	
Sex		
Female	12	
Male	4	
Humeral elevation	97 ±33°	130 ±15°
% Scapular UR	27 ±10	33 ±4
Upward rotation degrees	26 ±12°	42 ±5°
Psychological Constructs		
OSPRO-YF score		
PHQ-9	7.3 ±4.4	4.2 ±4.3
STAI	39.2 ±8.5	34.7 ±8.4
STAXI	13.8 ±2.4	14.1 ±2.7
FABQ-PA	20.1 ±5.1	12.2 ±6.8
FABQ-W	25.8 ±7.7	13.4 ±9.0
PCS	22.8 ±9.1	12.3 ±9.9
TSK-11	29.0 ±6.0	22.1 ±5.2
PASS-20	52.1 ±13.7	25.7 ±18.9
PSEQ	32.6 ±12.5	41.3 ±13.2
SER	96.9 ±11.9	99.1 ±18.8
CPAQ	53.4 ±12.1	69.3 ±21.2
Dependent Variables		
Total ASES score (0-100)	32 ±17	76 ±16
Pain score (0-50)	17 ±11	40 ±14
Function score (0-50)	14 ±9	36 ±7

***UR*, Upward rotation; *OSPRO-YF*, Optimal Screening for Prediction of Referral and Outcomes Yellow-Flag; *PHQ*, Patient Health Questionnaire; *STAI*, State-Trait Anxiety Inventory; *STAXI*, State-Trait Anger Expression Inventory; *FABQ-PA*, Fear-Avoidance Beliefs Questionnaire for physical activity; *FABQ-W*, Fear-Avoidance Beliefs Questionnaire for work; *PCS*, Pain Catastrophizing Scale; *TSK-11*, Tampa Scale of Kinesiophobia; *PASS-20*, Pain Anxiety Symptoms Scale; *PSEQ*, Pain Self-Efficacy Questionnaire; *SER*, Self-Efficacy for Rehabilitation Outcome Scale; *CPAQ*, Chronic Pain Acceptance Questionnaire; *ASES*, American Shoulder and Elbow Surgeon**

Predictors of One-Year Postoperative Outcomes

Age, sex, and degrees of scapular upward rotation were adjusted for in each multiple linear regression analysis. The only model in which a variable was added after completing the stepwise regression was for ASES pain scores in which preoperative fear avoidance beliefs for physical activity (FABQ-PA) was included. This model was not significant. No variables were entered into the ASES function or ASES total model by the statistical software (Table 4.3).

Table 4.3 Final multiple linear regression models for ASES Pain, Function, and Total Score. (N = 16)

Variable	Constant	R Value	R^2	Beta	Beta CI95 Lower Boundary	Beta CI95 Upper Boundary	p-value	VIF
ASES Pain:	-27.41	.579	.093					
Age				.277	-.467	1.386	0.298	1.063
Sex				.100	-16.783	22.885	0.741	1.434
Scapular UR				-.001	-.690	.688	0.998	1.271
FABQ-PA				.602	.007	3.258	0.049	1.227
ASES Function:	57.99	.353	-.094					
Age				-.321	-.787	.233	0.259	1.007
Sex				.021	-10.037	10.713	0.945	1.228
Scapular UR				-.185	-.492	.276	0.550	1.236
ASES Total:	80.97	.014	-.233					
Age				-.012	-1.232	1.172	0.957	1.007
Sex				-.100	-28.615	20.291	0.717	1.228
Scapular UR				-.045	-.899	.911	0.989	1.236

***ASES*, American Shoulder and Elbow Surgeon; *R^2*, Adjusted R Square*; R*, Regression correlation value*; VIF*, Variance inflation factor*; CI*, Confidence Interval*; UR*, Upward rotation; *FABQ-PA*, Fear-Avoidance Beliefs for Physical Activity**

Discussion

This is the first study to use biopsychological modeling for understanding predictors of RSA outcomes associated with patient self-reported pain and function in subjects with CTA. The literature supports the inclusion of both physical and psychological testing preoperative surgical correction for rotator cuff (RC) related conditions.[297,305] Although our prediction model was not powered to show statistical significance due to limited return in patients at one-year, we conducted a secondary analysis (Wilcoxon Signed-Ranks Test) to provide insight into what biopsychological changes occurred preoperative to 1-year postoperative RSA (Table 4.4). The Wilcoxon Signed-Ranks Test indicated that 1-year postoperative humeral elevation ($z = 110$, $p = 0.004$), percent scapular upward rotation ($z = 116.5$, $p = 0.012$), degrees of scapular upward rotation ($z = 130.5$, $p = 0.001$), ASES pain scores ($z = 5.50$, $p = 0.001$), ASES function score ($z = 0.00$, $p < 0.0001$), ASES total scores ($z = 2.00$, $p = 0.001$), PSEQ ($z = 108.00$, $p = 0.039$), and CPAQ ($z = 123.00$, $p = 0.004$) were statistically significantly higher than their respective preoperative measures. The Wilcoxon Signed-Ranks Test also indicated that 1-year postoperative PHQ-9 ($z = 12.00$, $p = 0.004$), FABQ-PA ($z = 7.00$, $p = 0.002$), FABQ-W ($z = 4.00$, $p = 0.001$), PCS ($z = 7.00$, $p = 0.002$), TSK-11 ($z = 5.00$, $p = 0.001$), and PASS-20 ($z = 3.00$, $p = 0.001$) were statistically significantly lower than their respective preoperative measures, indicating favorable results.

Our secondary analysis can be used to justify future research seeking to explain what influences patient outcomes. We found that surgery not only improved pain and function but also improved psychological factors. We found significant differences in all ASES component scores which is the well-accepted standardized clinical assessment form in this patient population. The form allowed us to evaluate clinically meaningful differences rated by the patient. Similar to our results, a systematic review by Petrillo et al[73] also found statistically significant ASES improvements ($p < 0.05$) in patients undergoing RSA for a massive RC tear or CTA at 35.3 ±12.3 months follow-up. In 228 patients, preoperative ASES pain, function, and total scores average was 18.1 ±0.07, 15.7 ±0.6, and 29.4 ±5.2, respectfully and increased to 40 ±18.5, 31.8 ±14.8, and 72.2 ±4.1, respectfully.[73] Unfortunately, not all studies included the use of the ASES making it difficult to compare results across research. In a more recent systematic review in patients undergoing RSA for rotator cuff dysfunction, the authors excluded a single article that used the ASES because the ASES was not the same scoring systems as used by the other authors.[72]

Multiple variables have been reported to predict surgical outcomes in patients with RC conditions which are important to consider as these studies can help set examples for future arthroplasty research projects. Many factors such as arm dominance, sex, alcohol use, ASA class, Simple Shoulder Test, ASES scores, prior shoulder surgery, humeral head displacement, glenoid type, diabetes, RC tear in those with glenohumeral osteoarthritis, and postoperative Four-dimensional Symptom Questionnaire for mental health have been found to be associated with outcomes.[51,57,58,60,62] Furthermore, work related factors such as workers compensation claims[51,306-308], fear-avoidance behavior related to work[57], and autonomy at work[309] were shown to predict functional outcomes after surgery in patients with RTC tears. Matsen et al determined that a shoulder problem related to work was a stronger predictor than the SF-36 Mental Component Score and self-reported anxiety and/or depression.[60] Unfortunately, none of these studies used a biopsychological to reach their conclusions on patient reported outcomes.

Greater emphasis is being placed on patient-reported outcomes after RSA by orthopaedic surgeons. A more thorough understanding of the role of psychological comorbidities on postoperative outcomes is necessary. Pain-associated psychological distress adversely influences functional outcomes and is a predictor of disability and health for patients with shoulder pain.[146] Best practice guidelines now include the assessment of psychologic conditions to prevent delayed recovery or potential transition into pain chronicity.[63] Despite consistent evidence in psychological factors being strongly correlated with change in pain intensity and amount of physician visits than tissue related injuries, assessment of pain-associated psychological distress is not routinely performed as a standard part of orthopaedic clinical practice.[63] In this study, we used the OSPRO-YF to examine the potential role of psychological constructs on patient reported outcomes assessed by the ASES after RSA. A benefit of the OSPRO-YF is that it is a 17-item questionnaire derived from a 136-item bank developed from validated psychological questionnaires across multiple domains related to pain vulnerability and resilience.[63] This tool assesses psychological constructs with low respondent burden. Higher OSPRO-YF scores indicate higher psychological distress as evidence of higher pain vulnerability and lower pain resilience.[64] The OSPRO-YF is a foundational assessment tool that mitigates difficulty in establishing psychological clinical factors that are missing from large-scale datasets for musculoskeletal pain.

Additional psychological measurement tools utilized in the literature include the Perceived Stress Scale (PSS) and the Brief Resilience Scale (BRS). The PSS is a valid measurement for perception of stress in an individual's life.[310] Styron et al examined preoperative PSS scores, SF-12-MCS and patient confidence in reaching their desired level of function 6-months following a TSA.[311] The primary predictor of function, measured by the Penn Shoulder Score, was baseline confidence in obtaining a desired postoperative level of function.[311] The authors failed to report preoperative diagnosis and indications for undergoing TSA which did not allow for ease of comparison. Confidence in surgical outcomes was also found to be a greater PRO predictor in the study by Thorpe et al.[51] Tokish et al analyzed resilience in patients who had undergone a TSA using the BRS, a 6-question Likert scale that classifies patients into normal-resilience, low-resilience, and high-resilience.[312] The BRS has proven reliability but lacks validity studies in English and disease specific normative values.[313-315] Although the authors showed that patients with high resilience demonstrate ASES scores up to 40 points higher than patients who have low resilience, caution should be taken when generalizing the results of this study.[312]

The majority of the RSA literature on scapular kinematic data is comprised of assessing scapulohumeral rhythm (SHR) and scapular upward rotation. Previous research examining scapular motion difference in patients with an RSA and healthy individuals typically report lower SHR ratios.[227,254-256,260] These lower ratios were the result of higher values of scapular upward rotation during arm elevation when compared to healthy individuals .[227,254-256,260] Scapular compensatory motions can be disadvantageous to the shoulder-complex in the long-term and are important to examine when considering the longevity of the patient's shoulder after undergoing surgical correction. The scapula typically contributes to 30 percent of total arm motion and may partly compensate for loss of shoulder movement after RSA.[27,28,258] Therefore, more comprehensive studies need to be conducted to increase information on how the scapula contributes to the function of the prosthesis. This will then inform rehabilitation specialist on which scapular motor patterns to initiate to prevent failure of the prosthesis. Furthermore, de Toledo et al. (2012) reported that it is important to avoid the occurrence of scapular dyskinesis to ensure that the exercises performed by patients with an RSA are effective and beneficial.

This study controlled for age and sex as they have been found to be associated with RSA patient reported outcomes.[271] Friedman et al found that when controlling for age, men had better ASES total scores (mean difference = 7.58 points [95% CI, 5.27-9.89], $p < 0.001$) and when controlling for sex each 1-year increase in age was associated with an improved ASES total score by 0.19 points (95% CI, 0.04-0.34, $p = 0.011$). Physicians knowledge of these two clinical factors can be a component of patient counseling and allow them to establish patient expectations after RSA. Another potential clinical factor to consider is preoperative patient expectations. Coronado et al found that preoperative patient expectations were associated with postoperative functional outcomes suggesting that this may need to be targeted for enhancing recovery and self-reported outcomes in this patient population but was not captured in our study.[188]

Scapular upward rotation was also controlled for in our statistical model as studies have shown that scapular kinematics differ in patients with RSA when compared to healthy individuals or the patients contralateral arm.[227,256] Patterns of scapular motion tend to have lower scapulohumeral rhythm ratios compared to contralateral shoulders, showing greater upward rotation values.[227] Terrier et al used 3D computational modeling and found that a portion of the mobility at the glenohumeral joint is transferred to the scapulothoracic region in computer generated shoulders after an RSA.[251] It is agreed upon in the literature that kinematics of the glenohumeral joint are significantly altered in a shoulders implanted with an RSA in which more scapulothoracic motion is used to help achieve arm elevation.[254,255,258,260]

Table 4.4 Secondary Analysis of preoperative to 1-year postoperative changes (N = 16)

Independent variables	p-value	Effect Size	Test statistic
Humeral elevation	0.004*	1.38	110.00
% Scapular UR	0.012*	0.85	116.50
Upward rotation degrees	0.001*	1.88	130.50
Psychological Constructs			
OSPRO-YF score			
PHQ-9	0.004*	0.72	12.00
STAI	0.098	0.54	36.00
STAXI	0.796	0.12	73.00
FABQ-PA	0.002*	1.34	7.00
FABQ-W	0.001*	1.49	4.00
PCS	0.002*	1.11	7.00
TSK-11	0.001*	1.23	5.00
PASS-20	0.001*	1.62	3.00
PSEQ	0.039*	0.68	108.00
SER	0.438	0.14	83.00
CPAQ	0.004*	0.96	123.00
Dependent Variables			
Total ASES score (0-100)	0.001*	2.75	2.00
Pain score (0-50)	0.001*	2.00	5.50
Function score (0-50)	<0.0001*	2.75	0.00

*** Significant difference $p < 0.05$**
***UR*, Upward rotation; *OSPRO-YF*, Optimal Screening for Prediction of Referral and Outcomes Yellow-Flag; *PHQ*, Patient Health Questionnaire; *STAI*, State-Trait Anxiety Inventory; *STAXI*, State-Trait Anger Expression Inventory; *FABQ-PA*, Fear-Avoidance Beliefs Questionnaire for physical activity; *FABQ-W*, Fear-Avoidance Beliefs Questionnaire for work; *PCS*, Pain Catastrophizing Scale; *TSK-11*, Tampa Scale of Kinesiophobia; *PASS-20*, Pain Anxiety Symptoms Scale; *PSEQ*, Pain Self-Efficacy Questionnaire; *SER*, Self-Efficacy for Rehabilitation Outcome Scale; *CPAQ*, Chronic Pain Acceptance Questionnaire; *ASES*, American Shoulder and Elbow Surgeon**

Limitations

The primary limitation of this study was the lack of a sufficient sample size due to low enrollment and 70% follow up rate. This did not allow us to generate a well powered statistical model to draw predictive conclusions from. It is important to note that patients presented postoperatively with potentially confounding health circumstances. For example, one patient had to undergo a hip replacement 11 months after undergoing RSA, placing her in a wheelchair with repetitive chronic use of her shoulder. This led to her reporting shoulder pain at 1-year when she believed she was otherwise improving. One patient developed moderate cervical stenosis which could potentially lead to limited shoulder function. Another patient was limited in ADLs due to undergoing wrist surgery 11 months after RSA. We also found that a couple patients were unable to be active due to cardiovascular conditions such as with a cardiac aneurism. These circumstances may have caused a result in lower ASES scores even though they were not directly related to their shoulder condition. Patient's may have reported higher pain levels and lower function scores due to these indirect conditions.

Strengths of this include the use of a clinical measurement technique for measuring scapular upward rotation preoperatively and 1- year postoperative. We are the first study to clinically measure scapular motion preoperative and 1-year postoperatively in this patient population. The majority of studies that have measured scapular motion in patients with an RSA utilized 3D motion analysis in the postoperative phase. These studies also have only compared motion to the contralateral shoulder or healthy individuals. Another strength includes the comprehensive psychological screening which had yet to be conducted in this patient population. Future projects should include a larger sample size with the help of using a multi-site study to enhance and broaden recruitment. This will then allow for the inclusion of more clinical variables into a prediction model to determine which factors physicians should focus on thus allowing them to be able to take control early on in postoperative management. Advances in this area are truly beneficial to both the patients and treating clinicians.

Conclusion

In an era of personalized medicine, future projects that fulfill the limitations of this study will aid in the development and implementation of future multidisciplinary studies aimed at generating evidence-based treatment protocols. The use of a biopsychological prediction model can be used by physicians to adequately make clinical decisions and tailor preoperative treatment according to the severity of the pathology, pathomechanics, and psychological state of the patient.

Chapter 5: Summary

The primary purpose of this dissertation was to examine the association between clinical biopsychological impairments with American Shoulder and Elbow Surgeon (ASES) pain scores, ASES function scores and total ASES scores in patients with small to massive rotator cuff tears. The secondary purpose was to investigate a biopsychological model for predicting worse ASES pain scores, ASES function scores, and total ASES scores one-year after undergoing a Reverse Shoulder Arthroplasty (RSA) for Cuff Tear Arthropathy (CTA).

Hypotheses and Findings for Specific Aim 1

Hypothesis 1: The combination of increased scapular anterior tilt during arm elevation and increased FABQ-PA scores will be significantly associated with worse ASES pain scores

Finding 1: This hypothesis was partially accepted, as increased FABQ-PA was associated with worse ASES pain scores but decreased scapular posterior tilt during arm elevation was not. However, it was found that decreased scapular external rotation during arm elevation was associated with worse ASES pain scores. We were correct that both a psychological and biological factor were affecting ASES pain scores, it was just a different scapular plane of motion.

Hypothesis 2: The combination of increased scapular upward rotation during arm elevation and decreased scapular external rotation during shoulder external rotation will be significantly associated with lower patient reported function scores measured by the ASES.

Finding 2: This hypothesis was not accepted. We found that younger age, less humeral elevation, decreased scapular external rotation during arm elevation, and lower scores in chronic pain acceptance were associated with lower ASES function scores.

Hypothesis 3: The combination of increased scapular upward rotation during arm elevation and increased FABQ-PA scores will be significantly associated with wrose total ASES scores.

Finding 3: This hypothesis was partially accepted in that FABQ-PA was associated with wrose total ASES scores. We also found that lower degrees of humeral elevation, decreased scapular upward rotation and decreased scapular external rotation during arm elevation were significantly associated with lower ASES total scores.

Hypotheses and Findings for Specific Aim 2

Hypothesis 1: Increased FABQ-PA will be most predictive of ASES pain scores

Finding 1: This hypothesis was not supported due to a lack in statistical power to be able to show clinical relevance.

Hypothesis 2: Increased scapular upward rotation during arm elevation will be most predictive of worse ASES function scores

Finding 2: This hypothesis was not supported due to a lack in statistical power to be able to show clinical relevance.

Hypothesis 3: The combination of increased scapular upward rotation and FABQ-PA will be predictive of worse total ASES scores one-year after RSA

Finding 3: This hypothesis was not supported due to a lack in statistical power to be able to show clinical relevance.

Synthesis and Application of Results

The overall purpose of this dissertation was to determine which clinical biopsychological factors are associated with worse ASES pain scores, ASES function scores, and ASES total scores. Based on our findings, multiple conclusions can be drawn from the first aim. In patients with RC tears, we used the pain, function, and the total outcome components of the ASES to examine which biopsychological factors are associated with each component of the ASES score. The implications of these results are that self-reported assessment scores are influenced by a combination of biological and psychological factors. It would be unjust to solely evaluate a single clinical factor such as arm elevation in attempt to explain ASES function. It will be more beneficial to employ a biopsychological approach during the examination process when a clinician is deciding which treatment course to take. A biopsychological approach would allow the clinician to intervene on both biological and psychological factors that impact self-reported outcomes.

In our population with rotator cuff tears pain scores were mainly explained by scapular external rotation and fear avoidance beliefs for physical activity (FABQ-PA) but of the two explanatory factors, FABQ-PA held the greatest weight in the regression model. Both regressions predicting the ASES function model and ASES total scores model were explained by at least one scapular motion and one psychological factor, with the psychological factor having the greatest weight contributing to the coefficient of determination. This study highlights that new clinical variables of psychological and scapular motion may be necessary to assess at patient's initial evaluation. It appears these measures affect ASES scores and may need to be addressed prior to surgery or during postoperative rehabilitation to facilitate the best possible outcome as measured by the ASES. These results can then be used by health care providers to support the future use of clinical psychological screening in the orthopaedic setting. Any form of psychological distress can have negative implications in how well a patient responds to treatment. Chronic pain acceptance and fear avoidance beliefs were the two psychological constructs found to influence ASES scores. Chronic pain acceptance has not been previously demonstrated in the literature as a contributing psychological factor associated with outcomes. Therefore, the OSPRO-YF helped reveal this new information. Cognitive behavioral therapy may help in reducing the amount of pain reported but future prospective studies are needed to determine this.

Additionally, in patients with cuff tear arthropathy, we were inadequately sampled to find significant biopsychological factors that predict each component score of the ASES form. However, we speculate that with an adequate sample size we would find that a biopsychological model is more predictive of patient reported outcome score. Our biopsychological prediction model can still be used to allow health care providers to adequately make clinical decisions and tailor preoperative treatment according to the severity of the pathology, pathomechanics, and psychological state of the patient. Surgical intervention certainly is impactful on patients but determining success or failure without better understanding the role of a patients physical and psychological well-being may not tell the complete story of a poor or successful surgical outcome in the eyes of the patient. In our secondary analysis conducted in order to determine if patients undergoing RSA improved one year after surgery, we ran a Wilcoxon Signed-Ranks Test comparing preoperative variables with 1-year postoperative results. All independent and dependent variables showed statistically significantly differences except for STAI, STAXI, and SER.

It can be inferred with reason that the results from our secondary analysis found that a Reverse Shoulder Arthroplasty not only improved pain and function but also improved psychological factors as well. These biopsychological factors could have improved as a result of the potential pain-relieving benefits of surgery. As clinicians we strive to improve quality of life in patients seeking treatment. The negative emotional, financial, and social aspects that are incurred in patients with rotator cuff conditions brings about multiple challenges during the course of treatment. When the patient’s physical and mental state are improved by successfully treating their underlying condition, the patient’s quality of life can been enhanced.

Appendices

Appendix A. Bivariate correlations of independent and dependent variables (N = 50)

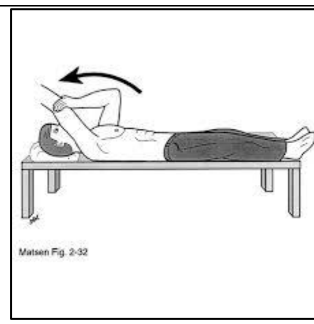
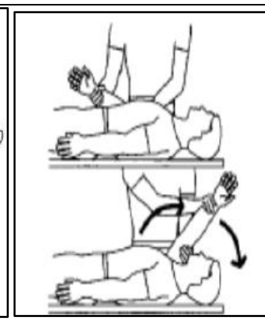
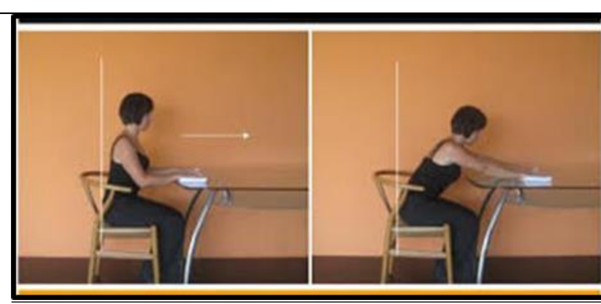
Dependent Variables	**ASES Pain**		**ASES Function**		**ASES Total**	
Independent Variables	Pearson (r)	p-value	Pearson (r)	p-value	Pearson (r)	p-value
Age, y	.173	0.23	.136	0.35	.179	0.22
Sex	.227	0.11	.276	0.06	**.285**	**0.05***
Anterior-posterior tear size, mm	.219	0.13	-073	0.62	.099	0.50
Transverse tear size, mm	.244	0.09	-.079	0.59	.112	0.44
Area tear size, mm	.221	0.12	-.065	0.65	.104	0.47
Humeral elevation	**.381**	**0.006***	**.612**	**<0.0001***	**.556**	**<0.0001***
Shoulder ER	-.094	0.52	.218	0.13	.055	0.71
% Scapular AP	-.122	0.40	-.082	0.57	-.118	0.41
% Scapular IE	**.480**	**<0.0001***	**.490**	**<0.0001***	**.554**	**<0.0001***
% Scapular UD	.107	0.46	.048	0.74	.092	0.53
% TSHR	-.134	0.35	-.197	0.17	-.2186	0.20
OSPRO-YF score						
PHQ-9	**-.337**	**0.017***	**-.320**	**0.024***	**-.376**	**0.007***
STAI	**-.344**	**0.014***	**-.388**	**0.005***	**-.416**	**0.003***
STAXI	-.173	0.23	.106	0.47	-.053	0.71
FABQ-PA	**-.489**	**<0.0001***	**-.585**	**<0.0001***	**-.609**	**<0.0001***
FABQ-W	**-.358**	**0.01***	**-.562**	**<0.0001***	**-.515**	**<0.0001***
PCS	**-.389**	**0.005***	**-.489**	**<0.0001***	**-.497**	**<0.0001***
TSK-11	**-.397**	**0.004***	**-.534**	**<0.0001***	**-.525**	**<0.0001***
PASS-20	**-.456**	**0.001***	**-.594**	**<0.0001***	**-.593**	**<0.0001***
PSEQ	.190	0.19	**.565**	**<0.0001***	**.412**	**0.003***
SER	-.014	0.924	**.413**	**0.003***	.206	0.152
CPAQ	**.291**	**0.04***	**.597**	**<0.0001***	**.492**	**<0.0001***

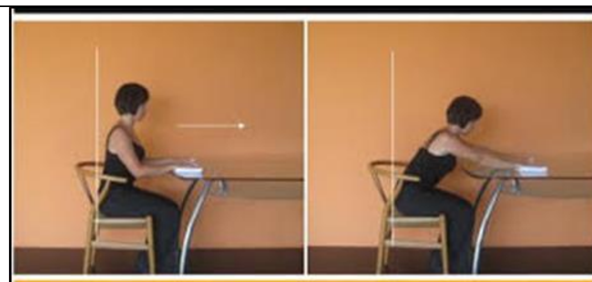
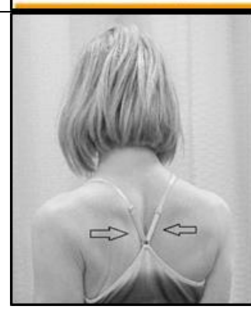
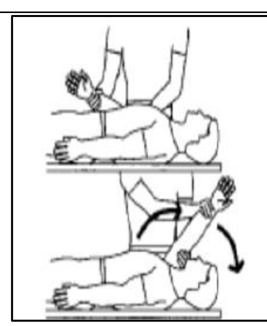
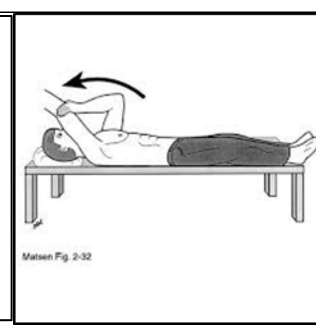
***ASES*, American Shoulder and Elbow Surgeon; *ER*, External Rotation; *AP*, Anterior/Posterior tilt; *IE*, Internal/External rotation; *UD*, Upward/Downward rotation; *TSHR*, Transverse Scapulohumeral Rhythm; *OSPRO-YF*, Optimal Screening for Prediction of Referral and Outcomes Yellow-Flag; *PHQ*, Patient Health Questionnaire; *STAI*, State-Trait Anxiety Inventory; *STAXI*, State-Trait Anger Expression Inventory; *FABQ-PA*, Fear-Avoidance Beliefs Questionnaire**

for physical activity; *FABQ-W*, Fear-Avoidance Beliefs Questionnaire for work; *PCS*, Pain Catastrophizing Scale; *TSK-11*, Tampa Scale of Kinesiophobia; *PASS-20*, Pain Anxiety Symptoms Scale; *PSEQ*, Pain Self-Efficacy Questionnaire; *SER*, Self-Efficacy for Rehabilitation Outcome Scale; *CPAQ*, Chronic Pain Acceptance Questionnaire
***statistically significant**

Appendix B. Shoulder Arthroplasty Therapy Protocol for Hemiarthroplasty, Total Shoulder Arthroplasty, and Reverse Shoulder Arthroplasty

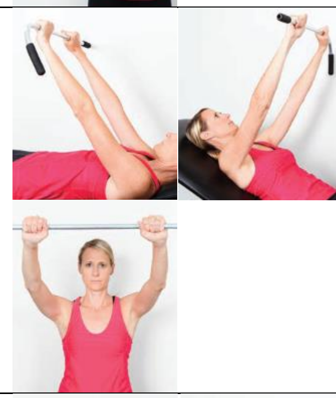
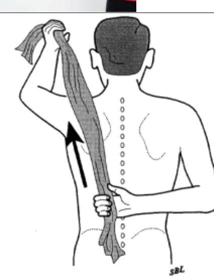
Patient to begin Phase 1 exercises at home daily, 5 times a day on the morning after surgery.

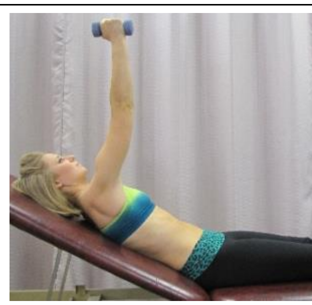
Phase 1	2 home based exercises	
Goals	Primary goal is for the tissue to heal through rest and only the perform the two exercises below.	
Patient Instructions for Daily Life	1. Remain in sling at all times unless showering or performing exercises. 2. We encourage the use of the ice or the cryo-cuff to help control pain and inflammation after surgery for a minimum of 6 weeks. 3. All exercises are performed 5 times a day for 5 repetitions.	
Therapist Instructions	1. Active assist shoulder exercises prevent stiffness and are critical for a good result. 2. Only these 2 shoulder exercises are to be performed 5 times a day for 5 repetitions 3. The following motions are not to occur: a) External Rotation past neutral b) Abduction c) Internal Rotation behind back	
0-6 weeks	1. Supine passive assistive forward flexion to 140° (ear level), hold 5 seconds and repeat 5 times, 5 times a day. This needs to be achieved within 2 weeks to avoid stiffness.	 
	2. Table slides hold 5 seconds and repeat 5 times, 5 times a day. This needs to be done pushing a small towel, getting arm to ear.	

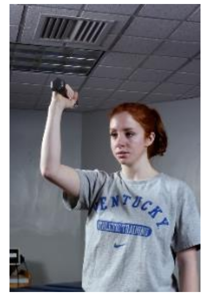
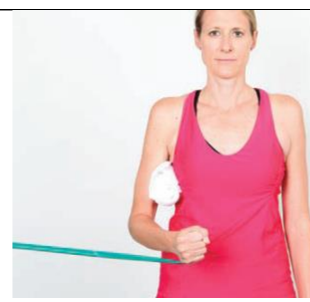
Week 6	**<u>Patient will see Dr. Hettrich prior to starting Phase 2 exercises</u>**	
Phase 2 Exercises	4 shoulder exercises are to be performed 2 times a day for 5 repetitions	
Goals	1. Continue healing after your surgery, as this takes 12 weeks. 2. Gain active motion of your arm with smooth movement without shrugging shoulders	
Patient Instructions for Daily Life	1. Use sling only in uncontrolled situations (crowds, around small children, animals) or on slippery surfaces (ice/snow) 2. All exercises are performed 3 times a day for 5 repetitions 3. Do not lift anything in your operated hand greater than 1 pound 4. No pushing/pulling 5. Need to keep arm in front of your body – no reaching to the side, reaching behind body, or pushing self-up from chair/bed	
Therapist Instructions	1. Exercises are to be instructed during a single visit and then the patient is to perform the following 4 exercises at home on their own.	
7-12 weeks	1. Table slides hold 5 seconds and repeat 5 times, 3 times a day to 140°	
	2. Scapular squeezes – Squeeze shoulder blades together for 5 seconds, 5 repetitions, 3 times a day	
	3. Supine passive assistive forward flexion to 140° (ear level), hold 5 seconds and repeat 5 times, 3	 

	times a day. If this has not been achieved it is imperative they do so ASAP.	
	4. Week 7-9: Ceiling Punches: Lie on your back reach your operated arm up toward the ceiling. Hold for 5 seconds repeat 5 times perform 3 times a day.	
	5. Week 10-12: Elevated Ceiling Punches: Replace exercise #4 with this exercise. Lie in a recliner or against propped up pillows. Lift your operated arm toward the ceiling and hold for 5 seconds, repeat 5 times perform this 3 times a day	

12 weeks	Patient will see Dr. Hettrich prior to starting Phase 3 exercises
Milestone	• *If Active Elevation to 90° in upright position cannot be performed 5 times in a row without scapular compensation start "Inability to Lift Arm Protocol" (Page 6)* • *If Active Elevation to 90° is performed without difficulty, then start Phase 3 exercises*
Phase 3 Exercises	1. Active motion exercises are to be performed for 10 repetitions, 3 times/day 2. Posture exercises should be held for 5-10 seconds and repetitions progress from 10-30 as tolerated, 3 times/day 3. Resistance exercise should be performed without substitution with light resistance progressing from 10-30 repetitions as tolerated 1 time/day
Goals	1. Restore active motion in multiple planes without pain or scapular substitution over the next 6 weeks 2. Initiate light strengthening exercises with short lever arm resistive exercises
Patient Instructions for Daily Life	1. No sling at all unless ice/snow 2. Use arm for normal daily tasks 3. Do not lift anything greater than 10 pounds with operated arm
Therapist Instructions	1. Patients may begin to restore their active range of motion by using active assistive devices such as a cane, pulley or the uninvolved arm in all planes. 2. Work on postural exercise and scapular retraction without overloading the shoulder 3. Progress active assisted motion from supine to wedge to upright as patient demonstrate smooth motion with no increasing in pain. Active motion may be performed in front of a mirror or using the opposite hand on the trapezius to prevent hiking of the shoulder. 4. Once active motion is well established and is pain free then light resistive exercises can be started. 5. The patient should work with therapist 1-2 times per week until released by surgeon, taking into consideration individual challenges, distance
Active Assistive Motion	4 exercises can be progressed from lying supine to wedge to upright as tolerated by the patient without increasing pain. Hold the cane with both hands. Elevate the arms using the healthy arm to guide the injured arm. Increase the use of the injured arm as directed by comfort. These exercise can be progressed to upright when comfortable.

	1. Assistive External Rotation – use stick if needed to rotate forearm away from the side hold for 5 seconds repeat 10 times 3 times/day.	
	2. Assistive Elevation – use stick if needed to reach overhead, hold for 5 seconds and repeat 10 times 3 times/day.	
	3. Assistive Abduction– use stick if needed to reach sideways overhead, hold for 5 seconds and repeat 10 times 3 times/day.	
	4. Assistive Hand behind back – use towel to gently pull your arm behind your back to gain motion in reaching behind you. Hold for 5 seconds and repeat 10 times 3 times/day.	 Matsen Fig. 2-36

Posture Exercises	Put hands on hips, lean back and hold for 5 seconds repeat 10 times, 3 times/day	
Resistive Exercises	1. Resistance exercise should be performed without substitution with light resistance progressing from 10-30 repetitions as tolerated 1 time/day. Start with short lever arm and progress to elbow straight 2. Elevation progression should be used if demonstrating compensation with active motion before progressing to elastic resistance exercises	
	Scapular retraction with light elastic resistance. Squeeze shoulder blades together while rotating arms apart from each other. Hold for 5 seconds, repeat 10 times, 2 times/day	
	Elevation Progression	
	a) Supine Punch – 0-2 pound weight punch up. Hold for 3 seconds, repeat for 2-3 sets of 10 repetitions. Once this is easy, progress to Wedge Punch.	
	b) Wedge Punch – 0-2 pound weight punch up. Hold for 3 seconds, repeat for 2-3 sets of 10 repetitions. Once this is easy progress to Standing Punch.	

	c) Standing Punch - 0-2 pound weight punch up. Hold for 3 seconds, repeat for 2-3 sets of 10 repetitions. Once this is easy progress to other resistive exercises.	
Elastic Resistance Exercise		
Resisted Outward Rotation	External Rotation While standing with involved elbow bent at 90°, place a towel between your side and elbow. Keeping the elbow in place at your side and bent at 90°, rotate involved arm outward to the side. Do not turn your body to the side as you rotate the arm outward.	
Resisted Inward Rotation	Internal Rotation While standing with involved elbow bent at 90°, place a towel between your side and elbow. Keeping the elbow in place at your side and bent at 90°, rotate involved arm inward toward your stomach. Do not turn your body to the side as you rotate the arm inward.	
Resisted Forward Punch	Flexion Anchor the ends of the theraband to the door to make a loop. Stand inside the loop with your back to the door. Place one-foot forward, use the left foot	

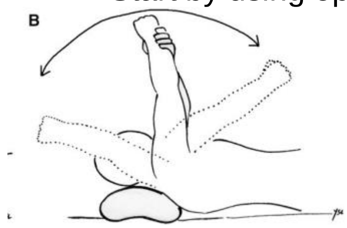
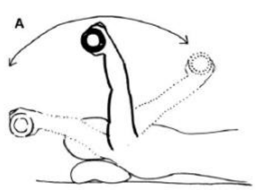
	for the right arm and reverse for the left arm. Punch your arm forward.	
Resisted Backward Shoulder Pull	Shoulder Extension While standing with both arms straight at your side, grasp the theraband in both hands. Keeping your arms straight, pull the theraband backwards behind you with both arms. Squeeze or pinch your shoulder blades together as you pull arms back.	
20-24 weeks/Phase 4 exercises	1. Continue to progress with resistive exercises through available pain free range of motion without substitution patterns 2. Initiate sport or work specific training activities 3. May lift up to 40 pounds	
	Precautions for weight lifting: 1. No overhead press exercises 2. No bench press with elbow past body (Rolled Bath Towel on chest) 3. No behind the neck squats	

Inability to lift arm Physical Therapy Protocol (Levy Protocol)

Instructions for Therapist

The patient should work with therapist 1-3 x per week until released by surgeon

Goals	The main goals of this physical therapy program are to: 1) Have the patient regain the ability to lift their arm against gravity without pain or substitution by progressing the patients through a progression of active arm mobility from gravity-minimized activities in supine to incline to upright active arm motion. 2) Although full motion may not be achieved by all patients the goal is to increase active arm mobility to normalize activities of daily living
Ice	We encourage the use of the ice or the cryo-cuff to help control pain and inflammation if needed

Questions/ Concerns	If you have questions or concerns, please contact the patient's physician, Carolyn Hettrick at 859-218-3054
Phase 1	• Perform exercises 5 times a day for 5-10 repetitions • Lie on back with head on pillow for comfort • Support or assist arm to straight up toward ceiling (90°) - May flex elbow if having difficulty with arm straight • Hold arm and gradually elevate toward head and lower toward feet with ability to return to straight up in the air, progress 1 inch at a time, to gain control of arm. - Start by using opposite hand for support  - Progress to performing without use of opposite hand through arc of motion (Therapist hands) 
Phase 2	• Perform exercises 5 times a day for 5-10 repetitions • Lie on back with head on pillow for comfort • Hold a can of soup in hand (dumbbell) with arm straight up to ceiling • Move arm through arc of motion with resistance. Start with 2 inches up and down, gradually increasing the arc as strength increases.  • In some patients, squeezing a ball between hands (subscapularis activation) or pulling light elastic resistance (infraspinatus activation) will overcome sticking points in the arc of motion. Return to using one are a soon as possible.
Phase 3	• Perform exercises 5 times a day for 5-10 repetitions

	• Lie on a wedge at 30° incline (or on top of approximately 2 pillows) • Move arm up and down through arc of motion 1. Opposite hand supporting 2. No assistance from opposite hand ○ With a soup can through an increasing arc of motion
Phase 4	• Perform exercises 5 times a day for 5-10 repetitions • Lie on a wedge at 60° incline (approximately 2 pillows against headboard/wall or in a recliner) • Move arm up and down through arc of motion 1. Opposite hand supporting 2. No assistance from opposite hand ○ With a soup can through an increasing arc of motion
Phase 5	• Perform exercises 5 times a day for 5-10 repetitions • Standing or sitting upright • Move arm up and down through arc of motion 1. Opposite hand supporting 2. No assistance from opposite hand ○ With a soup can through an increasing arc of motion

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Curriculum Vitae
Nicole Genevieve Cascia, MAT, LAT, ATC, CES

I. EDUCATION

Years	Institution	Degree	Specialty
2017 – 2020 (expected)	University of Kentucky	PhD	Doctorate of Rehabilitation Sciences
2016 – 2017	Texas Health Resources	Residency	Rehabilitation Athletic Training Residency
2014 – 2016	University of Houston	MAT	Master of Athletic Training
2010 – 2014	University of Houston	BSc	Kinesiology – Exercise Science

II. PROFESSIONAL and CLINICAL EXPERIENCES/APPOINTMENTS

Years	Institution	Role
2017 – 2020	UK HealthCare at Turfland – Orthopaedic Surgery & Sports Medicine, Lexington, KY	Research Assistant/Coordinator
2017 – 2020	Sports Medicine Research Institute, Lexington, KY	Research Lab Assistant
2016 – 2017	Texas Health Ben Hogan Sports Medicine Residency, Fort Worth, TX	Athletic Training Resident
2016 – 2017	Texas Christian University Sports Medicine, Fort Worth, TX	Assistant Athletic Trainer for Baseball team, Preceptor
2016 – 2017	Texas Health Ben Hogan Sports Medicine, Fort Worth, TX	Research Assistant for Upper Extremity 3D Lab, Clinical Assistant Athletic Trainer
2016 – 2017	Ben Hogan Sports Medicine Southwest Clinic, Fort Worth, TX	Research Assistant for Lower Extremity 3D Lab

2015 – 2016	Ironman Sports Medicine Institute – Memorial Hermann, Memorial City, TX	Assistant Athletic Trainer
2015 – 2016	Memorial Hermann Orthopeadic Medical Group, Sugar Land, TX	Assistant Athletic Trainer
2014 – 2016	Institute of Athletic Regeneration Ortho Manual Fellowship, Houston, TX	Fellow – Athletic Trainer
2014 – 2016	University of Houston Athletic Department, Houston, TX	Athletic Training Student, Baseball, Tennis, Basketball, Soccer, Football
2013 – 2014	Cole Health Rehabilitation, The Woodlands, TX	Physical Therapy Tech
2012 – 2013	The Woodlands Specialized Therapy and Rehab Services, St. Luke's Hospital, The Woodlands, TX	Physical Therapy Tech

III. TEACHING ACTIVITY

University of Kentucky:

Years	**Course number**	**Course Title**	**Role**	**Number of students**
Spring 2019	AT 690	Orthopedic Evaluation & Rehabilitation of the Upper Extremity	Teaching Assistant	11

Texas Christian University:

Years	**Course number**	**Course Title**	**Role**	**Number of students**
Fall 2016	KINE 30303	Orthopedic Assessment I	Teaching Assistant	12
Spring 2017	KINE 30313	Orthopedic Assessment II	Teaching Assistant	12

University of Houston:

Years	**Course number**	**Course Title**	**Role**	**Number of students**
2014 – 2015	ATP 6101	Anatomical Basis of Athletic Injury - Cadaver Lab	Teaching Assistant	20

IV. RESEARCH AND CREATIVE PRODUCTIVITY

PUBLICATIONS

Published Journal Articles:

Citation

1. **Cascia N**, Picha K, Hettrich CM, Uhl T. Considerations of Conservative Treatment After a Partial Ulnar Collateral Ligament Injury in Overhead Athletes: A Systematic Review. *Sports Health*. 2019; 1-8

2. Silverson O, **Cascia N**, Hettrich CM, Hoch M, Uhl T. Reliability of Clinical Assessment Methods to Measure Scapular Upward Rotation: A Critically Appraised Topic. *J Sport Rehabil*. 2018; 1-21.

3. **Cascia N**, Uhl T, Hettrich CM. Return to Play Following Non-Operative Management of Partial Ulnar Collateral Ligament Injuries in Professional Baseball Players: A Critical Appraisal Topic. *J Sport Rehabil.* 2018; 1-5

Referred Published Abstracts:

Citation

1. **Cascia N**, Takashima H, Yellen J, Knoblauch M. Common Plantar Digital Nerve Pain Due To Lumbopelvic Dysfunction in a Collegiate Baseball Player: A Case Report. *Southwest Athletic Trainers' Association Free Communications and Research Committee Research Supplement 2015*.

2. Silverson OA, **Cascia N,** Hettrich CM, Heebner, NR, Uhl TL. Reliability of a Clinical Assessment Tool for Measuring Scapular Mobility *Journal of Athletic Training, Volume 54, Number 6, Supplement 2019*.

3. **Cascia N**, Jacobs C, Ortiz S, Hettrich, CM, Wolf B. Poor Surgical Expectations for Patients with Shoulder Instability are Associated with Mental Health and Race. *Journal of Athletic Training, Volume 54, Number 6, Supplement 2019*.