COMPARISON BETWEEN STANDARD PHYSICAL THERAPY AND NEUROMUSCULAR RE-EDUCATION FOLLOWING ROTATOR CUFF REPAIR

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Abstract

Rotator cuff repair (RCR) is the most common shoulder procedure for which patients are referred for post-operative physical therapy (PT). Standard PT after RCR frequently consists of modalities, range of motion (ROM), and strength exercises. However, the optimal treatment approach has not been established. Neuromuscular re-education (NMR) is an alternative treatment to standard PT, but it has not been studied after RCR. The purpose of this study was to compare standard PT to standard PT and NMR to determine if NMR impacted selected clinical outcomes post-RCR.

A non-experimental retrospective case-control study was conducted to achieve this purpose. A convenience sample of patients who underwent PT following RCR was identified from electronic medical records. Active ROM (AROM), numeric pain rating scale (NPRS), and the Disability of the Arm Shoulder and Hand questionnaire (DASH) data were collected to determine if there were significant differences in these outcomes between the treatment groups and over time. Additionally, a change score was calculated and compared between treatment groups.

The change in AROM was significantly greater in the NMR group than the standard PT group (p = .024). The NMR group reached a greater level of clinically important change than the standard PT group (p = .006). There were no differences between the two groups for NPRS and DASH scores.

Results of this study suggest that NMR may help optimize AROM after RCR. Further research incorporating evidence-based treatment guidelines for NMR is needed to determine if NMR adds benefit to standard PT after RCR.

Keywords: rotator cuff repair, physical therapy, neuromuscular re-education, range of motion, proprioception, neuromuscular control

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A Comparison between Standard Physical Therapy and Neuromuscular Re-education Following Arthroscopic Rotator Cuff Repair

Rotator cuff repair (RCR) surgery is a frequently performed orthopedic procedure intended to restore the integrity of torn rotator cuff tendons, decrease pain, and restore functional shoulder mobility in individuals suffering from rotator cuff pathology.[1] This surgery continues to gain popularity where the number of RCR surgeries in the United States increased 141% in the decade from 1996 to 2006.[2] Despite the increased number of RCR surgeries performed and subsequent understanding of the timeline for healing, recovery after this surgery can be fraught with challenges.[3] Post-surgical challenges that may affect patient satisfaction with functional outcomes include post-surgical pain, loss of strength and mechanical stability at the glenohumeral and scapulothoracic joints, and loss of range of motion (ROM).[1,4] Following RCR surgery, physical therapists provide interventions to help patients manage their pain, prevent re-injury, and restore pain-free functional mobility.

During post-surgical care, physical therapists advise and assist patients in self-care, precautions to protect and promote healing at the repair site, pain management, and exercises to improve ROM and strength.[4-6] Physical therapy (PT) involves decreasing muscle inhibition and achieving voluntary control of the rotator cuff to achieve normal glenohumeral arthrokinematics during shoulder motion.[4,7] To accomplish this, PT may include cryotherapy, interferential electrical stimulation, passive range of motion (PROM), active assisted range of motion (AAROM), active range of motion (AROM) exercises, soft tissue and joint mobilization, and strength training.[1,5,6,8] These are all elements of what might be considered a standard PT approach for treating a patient following RCR surgery. Post-surgical guidelines for exercise progression, various exercises, and adjunctive interventions that help progress patients through recovery following RCR surgery can be found in published research studies.[1,6,7,9,10] For example, Pabian et al[1] and McCormick et al[10] suggested dividing the post-surgical program in four phases to assist therapists in deciding when to begin PROM, AROM, and strength training in a manner that protects the tendon graft. Several researchers recommended therapists communicate with the surgeon about the surgical procedure used prior to initiating treatment and use that information to individualize that patient's treatment plan based on additional factors including the patient's age, size of the rotator cuff tear, and comorbidities that affect recovery. [1,6,3]

Injury to or pathology of the shoulder joint and supporting structures may cause a deficit in proprioception and neuromuscular control of the shoulder.[11] Neuromuscular re-education (NMR) is an intervention used by physical therapists to improve proprioceptive characteristics, independent control of AROM, and joint stability.[12] This occurs through retraining motor output by stimulating motor input at the mechanoreceptors.[12,13]

Neuromuscular re-education has been more commonly studied in the ankle and knee joints than in the shoulder joint.[14-18] Numerous clinical trials of the ankle and knee provide support for the efficacy of NMR to significantly affect clinical and functional outcomes.[14-18] Borsa et al[12] recommended evidence-based evaluation methods and constructs for utilizing NMR for glenohumeral instability in 1994. However, since then there have been few studies evaluating proprioceptive impairment or the efficacy of using NMR exercises in the shoulder.[19-22] In particular, there has been a lack of research on proprioceptive deficits and the efficacy of using NMR to help restore ROM and dynamic stability following RCR surgery. Therefore, the purpose of this study was to compare a standard PT treatment approach to an approach using NMR to determine if PT treatment with NMR had an impact on clinical outcomes post-RCR surgery.

To address the study purpose, clinical outcome data from a multi-site national orthopedic organization were evaluated to determine if adding NMR to standard PT after RCR surgery, compared to standard PT alone, affected clinical outcomes. The following null hypothesis was tested: there will not be a statistically significant difference in clinical outcomes between patients who received NMR and standard PT compared to those who received only standard PT following RCR surgery. The specific outcomes tested were AROM shoulder flexion, pain measured with the numeric pain rating scale (NPRS), and shoulder function measured with the Disabilities of the Arm Shoulder and Hand (DASH) questionnaire.

This study is important because it provides preliminary data for future studies to examine for neuromuscular deficits following RCR surgery and to further explore the efficacy of using NMR exercises after RCR surgery. This is relevant to evidence-based practice to help the profession of PT stay current with the advancements and growing prevalence of rotator cuff surgery in orthopedic practice and for justifying NMR for third party billing.

Literature Review

There has been a considerable increase in the incidence of RCR surgeries over the past few decades.[2,23] Colvin et al[2] reported an increase in outpatient RCR surgeries from 58,846 in 1996 to 272,148 in 2006. This increase coincided with significant advancements in arthroscopic surgical techniques, and currently 95% of rotator cuff repairs are performed arthroscopically.[9] Along with this trend, several age-related and gender-related demographic characteristics of the RCR population have been reported in the general population.[2,24,25] There is a wide range in age of those individuals who undergo RCR surgery with this spanning from 12 years of age to 92 years of age in the general public.[23] Huberty et al[24] reported a median age of 55 years for a cohort of 489 Americans from the general population who underwent RCR surgery.

The authors of several studies reported that there is a disproportionate number of men compared to women in the general population who undergo RCR surgery.[2,24,25] Huberty et al[24] described 489 individuals who underwent this surgery where 67% were men and 32.9% were women. Colvin et al[2] and Brennen et al[25] reported similar proportions of men and women undergoing RCR as 56% and 44% respectively. In addition to age and gender-related demographics, duration of medical care data should also be considered when understanding the population who undergoes this surgery. Brennan et al[25] reported for 282 individuals who had RCR surgery, 24.5 days was the mean number of days between the day of surgery and the PT evaluation. For this same group of patients, the mean number of days between the date of surgery and PT discharge was 102.8 days. Additionally, these authors identified that the mean number of days between PT initial evaluation and discharge was 80.2 days, and the number of sessions of therapy was 14.8.[25] Boissonnault et al[26] reported a mean of 25 sessions over a 13-week time frame to complete a RCR rehabilitation protocol. There are several factors that may affect duration of care and account for the variability in duration of the rehabilitation protocol in particular.

The course of rehabilitation and outcomes may be affected by several risk factors. Of particular interest in the course of rehabilitation and outcomes is tendon healing. Successful tendon healing varies from 40% to 95% depending on the presence of risk factors.[3] Mulligan et al[3] reported the following risk factors predict poorer outcomes after RCR: age, smoking status, and the presence of comorbidities. Increased age was the most influential biological limitation to tendon healing, with the greatest risk of tendon failure in those over 65 years of age.[27] Other risk factors such as osteoporosis, hypertension, and obesity also significantly affect tendon healing.[3] The chronicity of the tear prior to surgery affects healing because morphological changes in the damaged tissue that effect the integrity of the tendon. However, the risk factor that has the greatest influence on the structural success or failure of a repair is the size of the tear prior to surgery, with larger tears presenting with a higher failure rate.[3] The mean number of comorbidities was 2.01 in a population of 118 patients after rotator cuff repair with the most reported comorbidities being obesity 84% and hypertension 43%.[26] Comorbidities may contribute to post-surgical complications and delayed recovery or failure of the repairs.

The most common complication after RCR is post-operative stiffness.[3] Risk factors that can lead to stiffness include age under 50 years, workers' compensation payer class, adhesive capsulitis or calcific tendonitis, and concurrent capsule-labral repairs.[24] Although, stiffness can be complicated to treat and painful for the patient, it can at least be managed with post-surgical rehabilitation such as PT and if necessary manipulation under anaesthesia.[3]

Post-Operative Standard Physical Therapy

Physical therapists have examined the post-operative management of patients after RCR and developed interventions to improve function in this population.[1] Currently available commentaries and research provide some information to guide care regarding use of modalities, immobilization, ROM, and strength exercise.[28-32] However, there is a lack of substantive clinical research to support the efficacy of an optimal treatment approach to standard PT interventions and post-surgical protocols after RCR.[28,32] In a systematic review of 11 randomized clinical trials of various post-surgical rehabilitation interventions, Thomson et al[32] reported there were a variety of PT rehabilitation programs aimed at restoring ROM, strength, and function. However, the heterogeneity of studies, variability in timing of measures, and variability in interventions made it difficult to compare the studies to determine an optimal approach to care. These authors concluded that while patients may expect a reduction in pain, increase in motion, and improved function after rotator cuff repair, there was no benefit found in favor of any one rehabilitation method. Additionally, higher quality randomized controlled trials with standardized treatment protocols and measures, longer follow up, and larger patient samples were recommended.[32]

Several treatments and management strategies such as continuous passive motion (CPM), splinting, and modalities have been evaluated and were found to provide no benefit to post-operative rehabilitation outcomes. Hayes et al[8] compared an individualized PT program to a home exercise program given by a surgeon. In this study, the control group was given a three-phase standardized home exercise program. Phase one consisted of elbow motion, grip exercise, scapular retraction, and pendulum shoulder movements. Phase two consisted of AAROM and isometrics. Phase three consisted of AROM, AAROM, and resisted-band strength exercises. The experimental group was given individualized PT treatment in addition to the home exercise program. The individualized treatment consisted of manual therapy techniques, any combination of exercise, ice, heat, and further advice on the home exercise program. Physical therapists determined the treatment content, rate of progression, and number of sessions. These authors found that a standard PT program provided no advantage to individuals than providing a home exercise program. In a study examining the use of CPM, there was no significant difference in outcomes between use of CPM on a CPM machine and a program consisting of manual PROM exercises.[29] Additionally, when CPM was combined with PT, there was no significant difference in time to achieve ROM goals compared to standard PT.[30] For this reason, the use of CPM is not recommended after RCR. With regard to the use of splinting after RCR, there was no difference when comparing a five-week post-surgical splinting protocol in abduction versus resting the arm in neutral for five weeks.[31] Some PT modalities have been supported in the literature while others have been found to have mixed results.[4,6,33] For example, in individuals with impaired muscle activation after surgery, electromyogram (EMG) analysis demonstrated that neuromuscular electrical stimulation (NMES) applied to the posterior cuff helped regain muscular control.[4] Also, cryotherapy was shown to result in less post-operative pain and need for narcotics.[33] However, the efficacy of transcutaneous electrical nerve stimulation (TENS), iontophoresis, and ultrasound remains controversial due to lack of well controlled clinical trials evaluating their role in the rehabilitation of those patients recovering following RCR.[6]

Clinical guidelines have been developed for post-surgical RCR care.[1] In these guidelines, phases of rehabilitation were identified to assist clinicians in their decision-making during the post-operative time period. Pabian et al[1] described several phases of rehabilitation: the maximum protection/passive phase, the moderate protection/active phase, and the minimum protection/resistive phase.[1] McCormick et al[10] described a slightly different protocol with a protected phase, ROM restoration phase, early strength phase, functional recovery phase, and a progressive return to sport phase. The pace of patient progression through the phases of recovery will vary between patients. Factors that affect this pace include the size, shape, and location of the tear, surgical procedure, tissue quality, and other patient characteristics such as age, comorbidities such as diabetes, and whether the patient smokes or not.[1,10] Pabian et al[1] evaluated EMG analyses and were able to identify various exercises and daily activities appropriate to improving ROM and strength in each phase of recovery. Guidelines for how much muscle activity was appropriate for each phase were given. Muscle activity was identified as a percentage of maximum voluntary isometric contraction (MVIC). According to Pabian et al,[1] exercises in phase one should demonstrate minimal activity (MVIC less than 20%), exercises in phase two should demonstrate moderate activity (20-40% MVIC), and exercises in phase three should demonstrate high activity (41-60% MVIC). Electromyogram analyses of activation patterns for shoulder muscles during shoulder exercises has been reported in other studies as well.[34-36] For instance, Wells et al[36] highlighted exercises and daily activities appropriate for the early phase of recovery. Reinold et al[34], reported optimal exercises for stimulating specific shoulder musculature. Side-lying external rotation (ER) produced the greatest amount of EMG activity for the infraspinatus and teres minor, and prone horizontal abduction at 100° with full ER produced the greatest amount of activity in the supraspinatus, middle deltoid, and posterior deltoid.[34] However, clinical trials in the patient population who have undergone RCR have not been conducted to test the efficacy of utilizing these exercises during the different phases of recovery to optimize ROM, strength, and function.

There has been focus in the literature on whether ROM exercises should be introduced in the first one to two weeks after surgery or be delayed to a safer period of four to six weeks in order to allow time for the graft to heal.[1,6,9,37] While there was some disagreement as to whether to start exercising in early phase to prevent shoulder stiffness or to wait until a safer period to prevent a breakdown in repair, there does not appear to be a greater benefit to either strategy according to Cuff et al.[9] Clinicians should recognize that patient specific factors such as the presence of pre-surgical adhesive capsulitis or the size of the rotator cuff tear may influence outcomes, and a decision about when to introduce ROM should take these factors into account.[3,9,10] There is a need for more randomized clinical trials addressing standard PT interventions.[32] Additionally, standard PT interventions may only progress patients to a certain point in clinical and functional outcomes post-operatively. Alternative interventions such as NMR, which takes more of a neurological approach to care as opposed to a mechanical approach, should also be explored to determine if better outcomes may be achieved.

Neuromuscular Re-education

The objective of the NMR treatment approach is to enhance the function of the nervous system's interaction with the muscles and joints in the body.[12,13,20,38] Afferent neural function is the intake of neural information through the nervous system, and proprioception is the term commonly used to describe afferent neural information communicated from the peripheral nervous system to the central nervous system (CNS).[12,13] Proprioception includes three functional components each with distinct characteristics.[13] The first functional component is joint position sense; this is the ability to distinguish where a joint is oriented in space. The second is the sensation of resistance which is the ability to recognize the force generated within a joint. The third and last functional component is kinesthesia or kinesthetic sense which is the ability to recognize joint motion including when motion begins and when it ends, sudden motion, acceleration, and deceleration. All three sub-modalities are thought to be realized both consciously and sub-consciously and are components of the proprioceptive domain of neural information that is communicated to the CNS.[12,13]

Anatomy of the Neuromuscular System

The anatomy of the neuromuscular system is the basis for understanding proprioception and how NMR affects motion via the nervous system. The neuromuscular system encompasses the sensory, motor, and central integration and processing components at higher levels of the CNS.[13] Mechanoreceptors are the primary organ of proprioception at the joint level. There are intra and extra-articular mechanoreceptors located in joint capsules, ligaments, labrums, tendons, muscle bodies, encapsulating fascia, and skin. Mechanoreceptors convert mechanical tissue deformation in the form of a stretch, strain, or compression into neural signals which communicate with the CNS via afferent neural pathways. Intra-articular mechanoreceptors are located in non-contractile tissue such as the labrum, ligaments, or joint capsule and contribute proprioceptive information primarily at the end ranges of motion.[12,39] Examples of intra-articular mechanoreceptors are Pacinian corpuscles, Ruffini endings, and Golgi-tendon organ-like endings. Ruffini endings and Golgi-tendon organ-like endings signal information important for distinguishing joint position sense whereas Pacinian corpuscles signal information important for distinguishing kinesthetic sense. Extra-articular mechanoreceptors include muscle spindles and Golgi tendon organs (GTOs) which relay information about muscle length and tension as muscles contract and stretch. Muscle mechanoreceptors are stimulated at mid-ranges of motion, so they relay proprioceptive information important for joint position sense at mid as well as end ranges of motion.[12,13,39]

Procedures used to examine sub-modalities of proprioception may help with understanding the afferent function of the neuromuscular system as it applies to the shoulder.

The test most often administered to determine kinesthetic sense is the threshold to detection of passive motion (TTDPM), which quantifies the ability of the CNS to consciously detect when motion begins. When there is a delay in the ability to detect when motion begins, this is called latency; it indicates that there is a deficit in kinesthetic sense.[12,13] Joint position sense is most commonly tested by measuring reproduction of active positioning (RAP) or reproduction of passive repositioning (RPP), which is the ability to actively or passively reproduce upper extremity angular motion. Reproduction of active positioning theoretically assesses the function of GTOs and muscle spindles since muscle contraction occurs. Reproduction of passive positioning theoretically assesses the function of Pacinian corpuscles, Ruffini endings, and Golgi tendon organ like endings, since the contractile tissues are at rest.[12]

Afferent information communicated from mechanoreceptors in the shoulder to the CNS may be combined either at higher brain centers or in the spinal cord. When this occurs at the level of the spinal cord, this allows complex and isolated movements that are repeatedly practiced to eventually be performed without reference to consciousness.[12,13,40-42] Organs at the higher brain centers that communicate with the neuromuscular system in the shoulder include the motor cortex, basal ganglia, and cerebellum. Cognitive awareness of limb and body movement and position mediate higher brain centers, which then initiate, program, and store voluntary movements as central commands.

Neuromuscular Control

Neuromuscular control is the unconscious activation of the muscles, which occurs in preparation for joint stabilization or movement, and is in response to the afferent input from joint motion and loading.[13] Where proprioception describes the afferent function of the neuromuscular system, neuromuscular control describes the efferent function, or motor output of the neuromuscular system needed for joint stability. Several mechanisms of the neuromuscular system are influenced by neuromuscular control. Co-activation is the simultaneous contraction of antagonistic muscles. When the rotator cuff and the antagonistic deltoid or the pectoralis and the antagonistic trapezius are synergistically activated at the glenohumeral or scapulothoracic joint, co-activation enhances glenohumeral and scapular stability, thereby improving reaction to external load or control of shoulder motion.[13]

Control of shoulder motion may also be enhanced by performing exercises that activate the spinal reflex arc. The spinal reflex arc results from afferent neural signals originating at the mechanoreceptors in the joint capsule, tendon, and ligament that rapidly travel to the spinal cord and back resulting in a muscle contraction around that joint.[12] Jerosch et al[43] arthroscopically demonstrated a spinal reflex arc between the shoulder musculature. However, the spinal reflex arc may not be fast enough to produce immediate joint stability when the joint is compromised. Instead, pre-programmed motor patterns that are received from higher levels of the CNS effective in altering joint motions are thought to be adjusted by the spinal reflex arc. In doing so, it is believed to assist programmed motor patterns through a diminishing function, which helps prevent harmful movements by improving preparatory and reactive abilities of muscles.[12]

Preparatory muscle contraction and muscle stiffness. Preparatory muscle contraction or pre-activation and muscle stiffness results when proprioceptive feedback from previous experiences is learned and stored at the higher brain centers and is then used for planning and executing motions.[13] Imagery exercise is a form of exercise which demonstrates a link between stored motor commands in the motor cortex and preparatory muscle contraction. During imagery exercise, a person mentally imagines a motion rather than physically performing the motion. Khademi-Kalantari et al[44] used EMG to demonstrate that imagery exercises activate shoulder muscles, which illustrates the connection between the motor cortex and muscle pre-activation. Planning and execution of motions help enhance muscle stiffness which assists joint stability, heightens muscle spindle sensitivity, and enhances reflexive joint stability.[44]

Components of neuromuscular control may be understood by discussing procedures used to test them. To assess the functionality of the spinal reflex arc, one method uses EMG to measure muscle activation patterns in response to joint perturbation to determine if muscle response latency exists after an injury or during rehabilitation.[13] Active ROM also assesses neuromuscular control; it may be examined with motion analysis software, goniometry, or an inclinometer. Active ROM may be an indicator of the effectiveness of co-activation of muscles at the glenohumeral and scapulothoracic joint. Muscle performance tests such as strength, torque, work, or power measure the force generating capacity of the muscle and the velocity of contraction. Muscle performance tests may be associated with pre-activation ability in muscles and may be measured in the laboratory with isokinetic dynamometry.[13]

Functional measures such as the functional throwing performance index (FTPI) and the single arm dynamic stability (SADS) test are used to assess dynamic shoulder stabilization. [13,20,21,45] Better throwing accuracy with the FTPI is correlated with superior neuromuscular control, where less corrections and falls during the SADS test is correlated with superior neuromuscular control.[13,20]

Factors that Adversely Affect Proprioception

Historically, authors of NMR research suggest that several factors affect proprioceptive feedback to the CNS, and proprioceptive deficits may occur when there is an alteration to the mechanoreceptors in and around a joint.[13,20,21,41] Based on what is known about proprioception, deficits are thought to occur after injury or pathology around the shoulder due to impairment of the mechanoreceptors. Exercise-induced fatigue was reported to alter proprioceptive feedback and neuromuscular control of the shoulder.[19,22,46] For example, Carpenter et al[19] used TTDPM to examine proprioceptive feedback at the shoulder after exercise induced muscle fatigue to the shoulder. They found TTDPM latency increased 171% for internal rotation and 179% for ER after fatigue, which supported the theory that fatigue effects sensation of joint movement (kinesthetic sense).[19] Meyers et al[20] theorized fatigue may also adversely affect neuromuscular control as measured with the SADS test. They reasoned that because fatigue hinders proprioceptive feedback from the shoulder to the CNS, the neuromuscular response and joint stability may be adversely affected.[20] Wickiewicz et al[22] performed kinematic analysis of glenohumeral motion after the shoulder muscles were fatigued and noted an increase in superior humeral head migration in the glenoid fossa at 45°, 90°, and 125° of shoulder scaption in standing. These authors considered from their results that fatigue may alter co-activation of opposing muscles at the glenohumeral joint resulting in a loss of dynamic stability.[22] These studies collectively illustrated how multiple factors may alter proprioceptive feedback and cause deficit in neuromuscular control.

The authors of several studies have examined the effect glenohumeral instability has on proprioceptive feedback.[22,47-50] Lephart et al[47] compared patients with chronic shoulder instability to individuals with healthy shoulders and patients with arthroscopically repaired shoulders after rehabilitation. The authors theorized proprioceptive feedback could be impaired in individuals with glenohumeral instability. Threshold to detection of passive motion and RPP were used to examine kinesthetic sense and joint position sense in each of these groups. They found that TTDPM was impaired in patients with chronic shoulder instability but not in healthy people or surgically repaired shoulder instabilities after rehabilitation ($p < .05$). They rationalized that damage to mechanoreceptors in the articular structure and soft tissues, believed to be common in shoulder instability, impaired proprioceptive feedback to the CNS. Mechanical instability as it relates to proprioceptive feedback has also been studied in the lower extremity of patients with anterior cruciate ligament (ACL) deficiencies in the knee.[51,52] Several authors have reported a deficit in proprioceptive feedback in patients with ACL deficiencies, and the anatomical evidence of nerve endings in the ACL suggests that it provides proprioceptive feedback to the CNS.[51,52] Researchers suggested that the symptom of giving way seen in the ACL deficient knee may at least partially result from the loss of this proprioceptive feedback and subsequent alteration of the spinal reflex arc.[51,52] Lower extremity studies further support the rational that if injury or pathology occurs to joints and the soft tissues that stabilize them that proprioceptive feedback is altered.[51,52]

The Role of the Rotator Cuff and Force Couples in Joint Stability

Proprioceptive feedback and resultant neuromuscular control is important to address during PT of the shoulder because the shoulder is inherently mobile and relies heavily on muscles and ligaments for stability and control of motion.[13] Rotator cuff muscles provide dynamic stability at the glenohumeral joint by producing forces that compress and centralize the humeral head within the glenoid fossa during shoulder motion. Specifically, these forces balance the pull the deltoid has on the humerus, which helps decrease upward migration of the humeral head during arm elevation.[12,13] The role the rotator cuff plays in stabilizing the humeral head during shoulder motion suggests it serves an important role in achieving neuromuscular control of the glenohumeral joint, preventing deleterious functional movement.

The shoulder's reliance on the rotator cuff for stability was examined in laboratory studies with digital fluoroscopic video (DFV).[53,54] Thompson et al[54] used DFV to examine if upward migration of the humeral head occurred during normal shoulder motion by measuring the distance between the acromion and the humeral head during shoulder scaption in healthy baseball players.[54] In particular, they measured the distance between the acromion and the humeral head which is called the acromiohumeral interval (AHI). These authors showed a progressive decrease in the AHI during scaption. However, when a load was added to the motion, the AHI did not change.[54] The authors rationalized that the rotator cuff helped to preserve the AHI when the extremity was loaded, which provided evidence to support the role of the rotator cuff to stabilize the humeral head while elevating the arm.

An EMG study supports the role of the rotator cuff for glenohumeral stability by examining activation of the rotator cuff to determine firing patterns during various arm motions. Reinold et al[34] used EMG in the laboratory to show peak percentages of MVIC of the rotator cuff muscles during seven shoulder exercises. All seven exercises resulted in EMG activation of the rotator cuff to varying degrees. The rotator cuff's role in stabilizing the humeral head during shoulder motion suggests an important role in achieving adequate, timely neuromuscular control of the glenohumeral joint during functional motion. While standard PT uses strength training to improve the function of the rotator cuff, neuromuscular exercises may optimize this stabilizing function of the rotator cuff.

Neuromuscular Re-education Exercise

Neuromuscular exercises may be used to improve proprioceptive feedback and restore adequate neuromuscular control at the shoulder. These exercises include rhythmic stabilization, active repositioning, resistive repositioning, and plyometric exercises. However, in the literature, there is confusion regarding the description of some of these exercises and conflicting descriptions of rhythmic stabilization versus dynamic stabilization exercises.[12,13,41,55] Rhythmic stabilization exercises may be defined as a group of exercises where a person tries to maintain joint position while outside forces or perturbations are applied to the extremity in order to stimulate joint and or muscle mechanoreceptors.[12] There are multiple purposes of rhythmic stabilization exercises. These include restoring co-contraction of the rotator cuff and scapulothoracic musculature, facilitating preparatory muscle activation, stimulating muscle reactive abilities via the spinal reflex arc, and promoting muscle stiffness in order to improve joint stability.[12,13] Rhythmic stabilization exercises are performed in both open and closed chain positions. Rhythmic stabilization exercise may be performed open chain with manual perturbations, closed chain on unsteady surfaces and different positions, closed chain with manual perturbations, or with shoulder movements on a variety of surfaces.[12,13,41,45,55] Open chain exercises can be performed in a variety of lying positions, in sitting, and in standing. Examples of closed chain body positions are the pushup position, plank positions, or tripod position. In addition to this, various surfaces such as the floor, wall, wobble board, sliding board, or therapy ball are appropriate to use. Externally applied perturbations or self-controlled movement may be performed at varying speeds during these exercises. Movements and perturbations may be performed in a safer more functional range or in positions of vulnerability in order to allow individuals to advance through a progressive rhythmic stabilization program.[12,13] Using a broad description of rhythmic stabilization helps avoid confusion when various positions and surfaces are evaluated for their effectiveness in shoulder conditions.

Rhythmic stabilization exercises stimulate the spinal reflex arc, which provides an elementary form of motor control for shoulder stability.[12,13] Naughton et al[41] evaluated the effects of stimulating the spinal reflex arc with rhythmic stabilization exercises performed in closed chain on a wobble board by individuals who had suffered shoulder dislocation. Before and after four weeks of an intensive rhythmic stabilization exercise program, researchers tested what they called active movement discrimination using active shoulder ER with the shoulder abducted 90° and in ER. Active movement discrimination assessed joint position sense, similar to RAP and RPP. After the training program, a statistically significant improvement in active movement discrimination was demonstrated in the experimental group ($p < .001$) but not in the control group ($p = .55$). The authors suggested from their findings that rhythmic stabilization in closed chain enhanced proprioception in a shoulder with instability and provided support that closed chain exercises stimulate both articular and muscle mechanoreceptors to increase reflex stabilization. Limitations of this study were that a control group was not used, and clinical or functional outcomes were not evaluated.

Dilek et al[56] used closed chain rhythmic stabilization exercises to evaluate the efficacy of proprioceptive exercises on the symptoms of sub-acromial impingement syndrome (SIS). The authors reported that the intervention group performed proprioception exercises, with all these exercises being in the form of closed chain rhythmic stabilization done on different surfaces. Individuals who performed rhythmic stabilization exercises along with a standard PT regimen were compared to individuals who received standard PT. Standard PT included electrical stimulation, heat, ROM exercises, posterior capsule stretching, and strength training. Authors evaluated RAP and RPP, AROM, strength, function, and pain pre and post exercise intervention. Both treatment groups showed significant improvement in clinical and self-reported functional measures after intervention. The group treated with rhythmic stabilization exercises had superior results to the control group in RAP and RPP but did not show significantly greater results than the control group in clinical or functional measures. The authors concluded that there may not be benefit to adding proprioception training to traditional PT in patients with SIS. However, the authors reported that specific exercise programs for proprioception may be included with SIS since individuals in the rhythmic stabilization group experienced better improvements in kinesthesia, RAP and RPP than the control group. The authors were not able to compute a sample size prior to initiating the study which may account for why they were not able to find a difference between groups for clinical and self-reported outcomes. While closed chain rhythmic stabilization exercises benefit the unstable shoulder, efficacy for use of this type of exercise in SIS is not fully supported here.[56]

Bae et al[57] evaluated an exercise protocol based on motor control theory to determine if adding this protocol to a strength program provided additional benefit to clinical measures and a self-reported functional outcome in individuals suffering from SIS. According to motor control theory, abnormal movement caused by damage or disease re-organizes the cerebral cortex leading to changes in the brain and uncoordinated movement. Therefore, exercise aimed at achieving normal motion control (motor control exercises) can help restore normal movement in patients with SIS. Bae et al[57] and Roy et al[58] suggested that when an exercise protocol based on motor control theory was performed, normal pain free movement could be achieved in this population. Bae et al[57] compared AROM, pain, strength, and functional outcomes pre and post intervention to test this hypothesis. They found a significantly greater effect on strength, AROM, pain, and self-reported functional outcomes after completing four weeks of strength training along with a protocol based on motor control theory compared to strength training alone. However, there were limitations to this study. For example, the description of the motor control theory protocol presented by authors in this study was not complete. Similar to exercises based on motor control theory, joint repositioning exercise is another form of neuromuscular exercise which may be used to enhance kinesthetic sense and joint position sense during shoulder motion.[13]

Joint repositioning exercises may include active or resisted joint repositioning. Joint repositioning exercise is where the extremity is brought through angular motion to a certain point in the person's available ROM to allow the person to familiarize with that point. Then the person is asked to reproduce that motion to the best of his or her ability with or without resistance.[13] Wilke et al[45] suggested using manually resisted concentric and eccentric internal and ER ROM exercises (resistive joint repositioning) at the glenohumeral joint. Although an increase in strength may result from performing these exercises, the emphasis of these exercises is not to increase strength since the exercises may be performed with a consistently low to moderate load to patient tolerance. The emphasis is on retraining joint position sense and kinesthetic sense by stimulating mechanoreceptors in the rotator cuff and articular structures. Borsa et al[12] suggested that resistive joint repositioning helps with learning motion and trains cognitive appreciation of joint position. Joint repositioning activities are initiated at the cognitive level and are thought to assist programming motor commands to voluntary movements. With consistent practice, joint re-positioning activities may stimulate conscious to unconscious motor programming in the higher brain centers resulting in better quality of motion.[12] Besides the research done by Bae et al,[57] there is lack of research to support the efficacy of joint repositioning exercise or to suggest when it is appropriate to initiate the use of these exercises in PT after RCR. While active and resistive joint repositioning exercise and exercises based on motor control theory are important to improve kinesthetic and joint position sense, plyometric exercises are intended to improve all aspects of the neuromuscular system.

Specifically, plyometric exercise is a dynamic form of neuromuscular exercise that enhances kinesthetic sense, increases dynamic muscle restraint around the joint, and enhances muscle pre-activation and stiffness.[40,42] The neuromuscular effect of plyometric exercise is potentiation of the concentric muscle action by use of the spinal reflex arc. Potentiation is the change in the force-velocity characteristics of the contractile components of muscles caused by a stretch of the muscles.[59] Additionally, plyometric exercises are thought to improve sub-conscious use of the central commands from higher brain centers.[40-42] Plyometric exercises are composed of three components: eccentric loading, amortization time, and concentric contraction. An example would be throwing a weighted ball against a trampoline, starting at shoulder height and progressing gradually to overhead throwing.[5] During eccentric loading, tension placed on the muscle spindles stimulates the spinal reflex arc, which is thought to enhance the neuromuscular response of the muscles in the shoulder. Stimulation of the spinal reflex arc during eccentric loading allegedly increases muscle force production by 10-15%.[5] Davies et al[46] reinforced the idea that the adaptation of the muscle spindles with the practice of plyometric exercise results in refined subsequent ballistic concentric muscle contraction during plyometric exercise. This results in reduced amortization time and improved motion velocity during both concentric and eccentric phases of muscle contraction.

Swanik et al[42] tested RAP and TTDPM to evaluate the effect plyometric exercises had on kinesthetic and joint position sense. After six weeks of training, they found significant differences between the control and experimental groups for both RAP and TTDPM at a reference position of 75° of ER and moving into ER ($p = .013$ and $p < .001$ respectively). Similar to what Vo et al[6] and Davies et al[46] had previously put forward, Swanik and colleagues[42] speculated that desensitization of GTOs in the joint capsule heightened stretch sensitivity of the muscle spindles which enhanced afferent communication to the CNS. They added that during plyometric exercise it was important to move the extremity through the entire range of motion in order to maximize proprioceptive feedback from muscle spindles and GTOs. This increase in afferent communication to the CNS formed peripheral adaptations at the spinal reflex arc and central adaptations at the cerebellum and basal cortex. Repetitive preparatory muscle activation in anticipation of catching the ball and involuntary muscle activity while throwing the ball contributed to central adaptations at the cerebellum.[42] These studies support the current rational for using plyometric exercise as a form of neuromuscular exercise once adequate strength is achieved.

Neuromuscular Re-education after Rotator Cuff Repair

There is evidence to support an association between rotator cuff tear and impaired proprioception at the shoulder.[60] However, there is currently a lack of research evaluating deficits in structure and function of proprioception in patients following RCR. Bachasson et al[60] evaluated several animal studies where tenotomy was performed on rabbit rotator cuff tendon, and based on their findings, they reported that rotator cuff tear was associated with structural and functional alterations of proprioceptors. Authors attributed impaired proprioception, kinematics, and muscle recruitment strategy at the shoulder complex to either reduced or inconsistent proprioceptive information from the injured tendon and altered muscle reflex activity.[60]

Ghodadra et al[5] advocated the use of NMR during certain phases of RCR rehabilitation to address these proprioceptive and neuromuscular deficits. Controlled activities that could safely activate the rotator cuff muscles, including submaximal and pain-free rhythmic stabilization exercises in the supine position were recommended. For rhythmic stabilization, the arm was placed in the balanced position, defined as 100° of shoulder elevation and slight horizontal abduction. The authors suggested that this position may have promoted the co-activation of surrounding shoulder muscles. In this position, the physical therapist applied perturbation in an alternating manner with an extremely low force of about 0.5 kg to 1.5 kg. Rhythmic stabilization for the shoulder internal and external rotators in the supine scapular plane position were also described to isolate co-activation of the rotator cuff muscles.[5] Wilke et al[45] and Borsa et al[12] recommended that rhythmic stabilization drills be performed in open and closed kinetic chain positions to optimize stimulation of muscle and articular receptors. Rhythmic stabilization may improve kinesthetic sense, pre-activation, and muscle stiffness of the rotator cuff, and surrounding shoulder muscles after surgery. The temporal adaptation may be improved dynamic glenohumeral and scapulothoracic joint stability.[12,45]

Currently, there is no consensus as to when it is appropriate to introduce NMR into a post-surgical RCR program. The decision relating to the timing of start of NMR may be based more on the type of NMR intervention being used and the individual circumstances of the patient. Zamani et al[44] suggested imagery exercise may be performed in the early protective phases of rehabilitation. The role of these exercises at this time may be helpful in preventing neural inhibition and disruption of motor control which are considered to be a common challenge for patients after RCR surgery. Vo et al[6] recommended gradually introducing most NMR exercises during the early strengthening phase of rehabilitation which is considered to occur 12 to16 weeks post-operatively. Vo et al[6] advocated the use of plyometric exercise at the end of the advanced strength training phase of RCR rehabilitation, 16 to 22 weeks post-operatively to allow adequate development of strength because of the ballistic stress placed on the tendon. The lack of consensus as to when to introduce NMR into a post-surgical program reflects the lack of clinical trials evaluating efficacy of NMR in those with shoulder pathology and after RCR surgery.

While the efficacy for the use of NMR in the RCR post-surgical population continues to be an area requiring research, the efficacy of NMR has been more thoroughly studied in the knee and ankle joints.[14,28,61-63] Zeck et al[14] reported in their literature review on NMR in the knee and ankle that various forms of NMR exercises effectively improved function as well as decreased the incidence of recurrent injury and episodes of giving way after recurrent ankle sprains and after ACL injuries. However, they also surmised that there were mixed results or no efficacy of training on joint position sense, neuromuscular control, joint laxity, and strength.[14] Risberg et al[64] examined if there was a difference between NMR and strength training after ACL repair. These researchers analyzed Cincinnati Knee Scores, the visual analogue scale (VAS) for pain, global knee function (VAF), strength, balance, and TTDPM. The NMR group demonstrated significantly improved Cincinnati Knee Scores and VAF scores after training. However, there was no difference in strength, balance, and TTDPM between groups after training.[64] Beard et al[51] examined the effect of NMR and strength training after ACL repair using a test that measured reflex hamstring contraction latency (a test of the efficiency of the spinal reflex arc), and the Lysholm and Gillquist Functional Scoring Scale for the knee. The authors discovered that there was a significant hamstring reflex latency in the acutely injured ACL. They attributed this latency to the deficit in proprioceptive input from the ACL or other proprioceptors within the joint. Both forms of exercise showed improvements in outcomes but a significantly greater improvement occurred in the NMR trained group. A limitation of this study was that it was difficult to identify what functional component of proprioception was trained based on the exercise description provided.[51] Ageburg et al[63] researched the effect of a NMR program on patients awaiting total knee or hip replacement with severe osteoarthritis. They assessed self-reported-outcomes and measures of physical function, and they compared the results to a control group who did not receive the intervention. The NMR trained group showed significant improvement in self-reported outcomes and measures of physical function compared to the control group.[63] These studies provide support that NMR may enhance muscle reflex, joint stability, and over-all function at the knee, hip and ankle after injury.[14,51,63,64] However, there were mixed results with respect to the effect of NMR exercises on proprioceptive components and the ability of NMR to improve results of tests of neuromuscular control at the knee and ankle. Some of the challenges in interpreting findings in NMR research include lack of clarity of theoretical framework for how exercises uniquely train components of the neuromuscular system and the lack of adequate exercise description.[14-18]

Clinical Outcomes

Clinical outcome measures and self-reported outcomes are used to assess change in patient physical impairment, perceived function, and disability during orthopedic care. Clinical outcome measures are used to assess change in a patient's physical function, while self-reported outcome measures indicate change in the patient's perceived of level disability and function.[65,66] In the shoulder, a clinical outcome measure may include AROM. Active ROM measurements indicate progress with healing, change in soft tissue flexibility, joint mobility, and neuromuscular control. Self-reported outcome measures include the DASH questionnaire and the NPRS. The DASH questionnaire and NPRS help determine how patients perceive their pain and functional ability.[67,68] In the orthopedic literature, clinical outcome measures and self-reported outcomes have been used in NMR and RCR research to evaluate change pre to post intervention and to establish if significant differences are present between treatment groups.[37,38,57]

Several authors have used ROM, self-reported pain scales, and functional outcomes in clinical trials to evaluate NMR for the shoulder similar to the methods used in the lower extremity NMR literature.[14,28,61-63] Bae et al[57] analyzed clinical and functional measures to assess efficacy of adding a NMR protocol to strength training in SIS. They evaluated the efficacy of this protocol by assessing changes in ROM, strength, self-reported pain, and the Shoulder Pain and Disability Index. Ginn et al[38] used a nine-question individually-standardized self-reported functional score in a group of patients with unilateral shoulder pain of local mechanical origin in addition to the clinical outcomes that Bae et al[57] used. Patients who completed NMR exercises were compared to the standard of care at the hospital where the study was conducted. The standard of care in this study was corticosteroid injection and a combination of electrophysical modalities, joint mobilization, and ROM exercises.[38] In these studies, both groups showed significant improvements in all of the measures after the intervention period.[38,57] Clinical measures and self-reported outcome measures successfully captured measurable change from pre to post NMR intervention in individuals with shoulder dysfunction. Additionally, in the study by Bae et al[57] authors discovered a statistically significant difference between treatment groups at post assessment periods for clinical and self-reported functional outcomes.

Keener et al[37] evaluated AROM shoulder flexion with standard goniometry in a group of 124 patients in several follow-up assessments after RCR. Patients were randomized to either a traditional PT protocol involving early PROM or to an immobilization group in which ROM was delayed for six weeks. At the three-month follow-up, the mean AROM flexion for the traditional PT group was 136° and 123° in the immobilization group (p = .02). At six months the traditional PT group had a mean AROM of 155° and the immobilization group mean was 159° (p = .61).[37] The authors of this study were able to detect clinical change in AROM flexion at follow-up time periods after RCR establishing validity of AROM measurement.

Brennan et al[25] evaluated changes in NPRS scores pre and post RCR rehabilitation in 341 patients to identify the clinical outcomes following standard outpatient PT and to examine the differences in outcomes between men and women. The authors reported that for males the mean NPRS score at evaluation was 4.9 and at discharge was 2.5 with a mean change of 2.5 points. For females, the mean NPRS at evaluation was 4.1 and at discharge was 2.0 with a mean change of 2.1 points. Statistically significant differences pre to post rehabilitation were found in both genders ($p < .05$) even though change score values were not statistically significantly different between genders ($p > .05$).[25]

Boissonnault et al[26] evaluated DASH scores pre and post a RCR rehabilitation protocol to assess the effect of comorbidities on functional outcomes. Patients received a protocol including therapeutic exercise, manual therapy, electrotherapeutic modalities, and physical agents. The authors reported that the mean DASH scores decreased significantly pre to post rehabilitation ($p < .001$) and that the number of comorbidities did not affect DASH scores.[26] No control group was used in this study. In the Brennon et al[25] study, there was a statistically significant decrease in mean DASH scores pre to post rehabilitation in males from 56.1 to 21.9 and in females from 63.9 to 28.9. These studies support that functional outcomes can detect changes pre to post intervention in patients who have undergone RCR.

In summary, it may be considered that adding NMR to standard PT care after RCR may positively influence clinical measures and self-reported outcomes. A significant gap in the broader post-operative RCR rehabilitation literature exists for randomized controlled clinical trials to support the optimal treatment approach for postoperative rehabilitation. The NMR approach may help optimize outcomes after RCR. Working to improve neuromuscular components of the system associated with control of the rotator and surrounding scapular musculature after surgery reduces deleterious humeral head migration during active shoulder motion and enhances joint stability, which can significantly affect post-surgical recovery. However, the optimal way to achieve this objective is less clear throughout the literature since there are few randomized controlled clinical trials to support NMR interventions, specifically in the post-operative RCR population. Therefore, these concepts need further research following RCR. Clinically, NMR may help improve the quality of motion during other PT exercise, reduce pain, mitigate the effects fatigue, and reduce chances of developing stiffness or graft failure. Retraining the cerebral cortex and motor commands, as was suggested by Bae et al,[57] may also help improve the quality and velocity of functional movements such as reaching behind the back or head and across the body.

Method

Study Design

A non-experimental retrospective case control study was conducted to determine if adding NMR to standard PT after rotator cuff surgery affected selected clinical outcomes when compared to patients who only received standard PT after their surgery. The study was approved by the University of Indianapolis Human Research Protection Program in December 2014. The electronic medical records (EMR) located at the central office of ATI Physical Therapy, a national private PT organization, was queried to identify potential participants. Data were collected from a five-year time frame (January 1, 2012 –December 31, 2016) The EMR system used by this private practice was developed by the information technology (IT) department of the practice and is proprietary to the practice organization.

Sample

A sample of convenience of patients between the ages of 25 to 75 years who received PT at an ATI facility following arthroscopic rotator cuff surgery between January 1, 2012 and December 31, 2016 was identified from the EMR. Based on an a priori sample size calculation (see section below), a minimum sample size of 122 (61 in each group) was required. Once a list of potential patients was derived from the query of the EMR, patients were screened for eligibility based on the following inclusion and exclusion criteria.

Inclusion criteria. The following inclusion criteria were used:

- Patient's age is between 25 and 75 years
- Patient received treatment and was discharged with the data collection dates
- The PT start date was with-in the first 10 weeks of the documented surgery date

- A PT start date with-in the first 10 weeks after surgery was chosen because research supports long-term outcomes are similar whether someone starts immediately or delays the beginning of therapy[1,6]
- A minimum of five visits of NMR and standard PT or standard PT only sessions were completed
- Based on studies investigating the use of NMR in the shoulder population, the aim was to include a minimum mean of 12 sessions of NMR in the experimental cohort[57,69]

Exclusion criteria. The following exclusion criteria were used:

- Previous history of ipsilateral rotator cuff surgery
- Infection in the ipsilateral shoulder present at the time of the PT evaluation
- Neoplasm in the ipsilateral shoulder
- Irreparable rotator cuff tear
- Incomplete repair of a rotator cuff tear
- Clavicular or scapular fracture present at the time of the PT evaluation[8]
- Current adhesive capsulitis
- Calcific tendonitis[24]
- Pain and/or paresthesia referred from inflamed structures in the cervical spine[38]
- Missing AROM flexion data at discharge

Patients were screened sequentially until 61 patients in both treatment groups were identified.

Sample size. An a priori sample size calculation was conducted using G*Power sample size calculator.[70] The calculation was based on shoulder AROM flexion using a two tailed independent *t* test, alpha of .05, power of .80 and a moderate effect size of .51. The effect size for the sample size calculation was based on data provided in a study by Bae et al[57] which looked at similar AROM flexion in individuals with sub-acromial impingement syndrome. From the calculation, it was estimated that a minimum of 122 participants (61 in each treatment group) was required for the study to achieve adequate power.

Data Collection

Both demographic and clinical outcomes data were extracted from the EMR for each participant selected. The demographic data were collected by physical therapists pre-treatment and included age, gender, body mass index (BMI), comorbidities, payer type, diagnosis description, surgical side, comorbidities yes/no, comorbidity number, the Functional Comorbidity Index (FCI) score, days from surgery to initial evaluation, days from surgery to discharge, days from initial evaluation to discharge, number of visits total/case, and number of visits standard PT/case. The clinical outcomes and self-reported outcomes were collected from both pre-treatment and post-treatment and included shoulder AROM flexion, NPRS scores, and DASH scores. These outcomes were collected by both physical therapists and physical therapist assistants responsible for treating the patients as part of their standard care. Active ROM data were used for analyses with the assumption that this would more accurately represent an improvement in neuromuscular control than PROM. The FCI was calculated using comorbidity data recorded by physical therapists as part of the patient's usual care. Data were collected from the index assessment and the discharge assessment. The index assessment was defined as the second post-surgical PT assessment within the study period. The second assessment period was chosen as the index assessment because frequently many surgeons and post-surgical protocol guidelines do not allow AROM measurement on the surgical side at the initial evaluation. The discharge assessment was defined as the last assessment in which the patient was discharged by the treating physical therapist. The data were originally recorded in Microsoft Excel and later exported to a statistical software program for analysis.

Operationalization of variables. For payer type, individuals were categorized as having either private, public, or other insurance. Individuals were categorized as other if the payer was part of personal injury, worker's compensation, or auto litigation. Individuals were categorized into one of three categories by their diagnosis description. The first category was Repair: RTC. The second category was Repair: RTC type II or III. The third category was Repair: complete rupture. Co-morbidity were recorded as present (yes/no) and was considered present if it was reported in the patient's EMR. For this study, 17 conditions identified in the FCI were considered to be a comorbidity. A list of these co-morbidities can found in appendix A. In addition, the number of different co-morbidities were also collected. These comorbidities were used to calculate the FCI score. The number of days from surgery to initial evaluation, days from surgery to discharge, and days from initial evaluation to discharge were calculated from surgical dates, evaluation dates, and discharge dates for each case.

Instruments

The following instruments were used to collect outcome measures: goniometer, self-reported NPRS, and the self-reported DASH. These outcome measures used for analyses in this study are clinical PT measures and self-reported outcome measures commonly used by clinicians. The organization's EMR prompts clinicians to take clinical measures every fourth visit and to enter the measurements into the EMR immediately after the measurement is taken.

Goniometer. Therapists employed by ATI are advised to use industry standard goniometric measurement techniques to take AROM measures.[71] To improve the reliability of clinical measures, ATI advises clinicians to take AROM measures at the beginning of the session. Goniometric AROM measurements in the shoulder, including flexion, have strong intrarater reliability values (ICC = .89 - .97).[66,72] Muir et al[66] reported good interrater reliability for AROM flexion measured in supine on individuals with shoulder pathology (ICC = .89). Mullaney et al[73] reported good interrater reliability of AROM shoulder flexion measured in the supine position (ICC = .93). In a study by Muir et al[66], the established minimal detectible change (MDC) for AROM shoulder flexion measured in supine on individuals with shoulder pathology was 12°,[66] and the standard error of measure (*SEM*) was four degrees. In this same study, the minimally clinically important difference (MCID) was found to be eight degrees.[66]

Numeric Pain Rating Scale. The NPRS quantifies patient-reported pain on an 11-point scale with scores that range from zero to ten. The scale is anchored on the left with the phrase “no pain” and on the right with the phrase “worst pain imaginable”.[68] A negative change in the NPRS is considered an improvement in pain with less pain reported. At ATI facilities, the NPRS was verbally delivered to patients at each office visit. Clinicians were advised to explain the set-up and direction of the NPRS to patients when they introduce it to them. The intrarater reliability of the NPRS for patients with a primary complaint of shoulder pain was strong (ICC = .74, 95% CI [.08, .92]).[65] Mean weighted kappa for interrater reliability was k = .48.[74] Kappa values between .41-.60 indicate the test provides moderate strength of agreement between observers.[75] Mintken et al[65] reported an MDC of 2.5 for the NPRS in patients with reported shoulder pain. In a study by Michener et al,[68] the MCID for the NPRS was 2.17 for patients with post-surgical shoulder pain.[68]

Disability of the Arm, Shoulder, and Hand. The DASH is a self-reported questionnaire used to measure upper extremity disability and symptoms. It consists of 38 items total with the main part consisting of a 30-item disability/symptom sub-scale.[67,76] Responses for each item are totaled, and the final score ranges from 0 (no disability) to 100 (severe disability).[67] Negative change in DASH is considered improvement in function. Clinicians working at ATI facilities are advised to deliver the DASH at the initial evaluation, at re-evaluations, and at discharge. Responses to the DASH are entered into the EMR which automatically calculates the DASH score. The DASH has been shown to be a highly responsive, valid, and a reliable measure of disability in patients with shoulder disability.[77] The authors of several studies evaluated the intrarater and interrater reliability of the DASH.[77,78] Intrarater reliability was determined to be strong in individuals with an upper humerus fracture (ICC = .92, 95% CI [.86, .96]).[77] Interrater reliability was established by Dixon et al.[78] In their study, 24 academic judges were asked to match the 38 items on the DASH to the definitions of the constructs of impairment, activity limitation, and participation restriction from the international classification of functioning disability and health (ICF). Authors reported interrater reliability for all judgements across all 38 items was at ICC = .96; 95% CI (.94 - .97).[78] In a study by Franchignoni et al[76] the MCID and MDC for the DASH was 10.83 points and 10.81 points respectively.[76]

Functional Comorbidity Index. The FCI consists of 17 comorbid diseases and is used in the general population to predict physical function as the primary outcome of interest. The premise behind the FCI is that comorbidities such as arthritis associated with physical function have more of an effect on physical function.[79] The 17 comorbid diseases reported on the FCI were able to predict the physical function subscale of the 36-item Short Form Survey (SF-36) which established the validity of this index to predict physical funcion.[79] Therefore, the index may be used in research to adjust for the effect of comorbidity on physical function similar to how other comorbidity indices are used to adjust for the effect of comorbidity on mortality.[79] The FCI was shown to be associated with self-reported functional outcome measures at baseline and at a 64-week follow-up in a group of 222 patients who sustained rotator cuff tears. Patients with higher FCI scores were associated with lower functional outcomes ($p = .025$) which showed it to be a reliable predictor of outcome in the rotator cuff tear population.

Procedures

All data were originally accessed from a database at ATI's central office where data from over 700 separate clinics were collected via the EMR network. After agreement from ATI's chief compliance officer, patient filed data were downloaded from the IT system by data developers of the Department of Research and Data Analytics of the organization. Patients who had rotator cuff surgery were identified in the EMR by common diagnosis description, international Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis codes, and International Classification of Disease, Tenth Revision. For those patients who received PT after the Fall of 2015, the Clinical Modification (ICD-10-CM) was used. The list of ICD-9 and ICD-10 codes used for query can be found in Appendix B. Patient files were pulled from the EMR based on common diagnosis descriptions and ICD-9-CM codes or ICD-10-CM codes that the evaluating physical therapist entered into the EMR at the same time of the patient's initial visit. Results of the query were sent to the author of this study in an encrypted Excel file from the research department. All the data had private health information (PHI) redacted per Health Insurance Portability and Accountability Act (HIPAA) standards to maintain patient confidentiality prior to the data being sent to the author of this study. The author checked files for inclusion and exclusion criteria and excluded patients who did not meet the specified criteria. Study participants were classified into one of two separate groups: (1) participants who received standard PT care and (2) participants who received standard PT care with NMR. With a large number of clinics spread out nationally, the author believed patient demographics, interventions, and clinical outcome data represented the larger population of patients who had RCR during the same time period.

Group assignment was based on current procedural technology (CPT) codes entered by physical therapists and physical therapist assistants at office visits for interventions given. The list of CPT codes used for query can be found in Appendix C. Using the data sample query from the EMR, the author formed two groups via the matching process. The standard PT group consisted of participants billed with one or more of the following CPT codes but never the code for NMR: cold therapy, electrical stimulation, manual therapy, therapeutic exercise, and therapeutic activities. The NMR group consisted of patients billed with CPT codes for NMR interventions in addition to one or more of the codes from the standard PT cohort. The intent was that this group reflected current literature for use of various exercises presented in NMR shoulder literature such as: rhythmic stabilization, plyometric, resisted, active, and passive joint repositioning exercise.[1,5,6,38-42,45,57,69,80]

Data Analyses

Descriptive statistics were conducted on the entire sample and then on both treatment groups. Nominal data are presented as frequencies and percentages and ordinal data as medians and interquartile ranges (IQR). Interval and ratio data are reported as means and standard deviations or medians and IQRs, dependent on whether or not the data were normally distributed. To determine if participants in both groups were similar in demographic characteristics, comparisons were conducted using a Pearson chi-square test for nominal data, and non-parametric tests for ordinal data (Mann-Whitney *U* test or Kruskal-Wallis test, as appropriate). Either an independent *t*-test or non-parametric Mann-Whitney *U* test were used for interval and ratio data, dependent on whether or not the data were normally distributed. If significant differences were found between groups using Pearson chi-square test, post hoc tests using the Bonferroni correction were conducted.

All three outcomes were compared between groups at both time periods and within groups. Because AROM values, NPRS scores, and DASH scores were not normally distributed at the index assessment or discharge assessment period, they were compared at both time periods using a Mann-Whitney *U* test. The Wilcoxon signed-ranks test was used to determine if there was a significant change in AROM values, NPRS scores, and DASH scores between the index assessment and discharge assessment period for both treatment groups. To determine if there was significant difference in the amount of change that occurred from the index assessment to the discharge assessment among the three groups, a change score (post-intervention score minus pre-intervention score) was calculated for each outcome. Change scores between the groups for AROM and NPRS were compared using the Mann-Whitney *U* test while change scores for the DASH were compared using independent *t* test.

Clinical relevance of the results was determined using established MDC and MCID values for each of the outcomes. In addition, effect sizes were calculated and reported for all clinical outcomes as a measure of experimental effect. Calculations were conducted using formulas provided by Cohen.[81] Interpretation of the effect size is as follows: .20 = small effect, .50 = medium effect, and .80 = large effect.[81]

Because significant differences in several demographics were found between the treatment groups, multiple linear regression was undertaken to determine if demographic variables had a significant impact on the clinical outcomes along with the treatment group. Explanatory variables that demonstrated a statistically significant difference or correlation with the clinical outcome variable were introduced into the regression model simultaneously using the

Enter method. Data screening and preliminary analyses were performed to confirm assumptions of normality, linearity, multicollinearity, and homoscedasticity. Multicollinearity was determined to be present if a correlation coefficient was greater than .80 and tolerance values were less than 0.10, and the assumption of independence of observations was met if the Durbin-Watson value was between 0.80 and 3.20.[82] Outcome data were transformed if they were not normally distributed. If there was multicollinearity between covariates, then based on bivariate correlation results, the variable with a higher correlation with the outcome was entered into the model and the other variable removed. Dummy variables were created for multinomial demographic variables for regression analysis.

Minimal detectable change scores for outcome variables reported in the literature for individuals with shoulder dysfunction were used to make cut off scores for outcomes. Dichotomous variables separating individuals who demonstrated clinically meaningful change from those who did not were created for each outcome measure based on these cut off scores.[65,66,76] A Pearson chi-square test was used to see if a statistically significant difference existed between treatment groups for these dichotomous variables. Individuals with change scores greater than the cut off score were determined to have demonstrated clinically meaningful change. Individuals with change scores greater than the cut off score, but where change was actually negative as determined by individual measure, were considered to have clinically worsened. Individuals with change scores that were less than the cut off score were determined to have clinically stayed the same regardless of the direction of change recorded. The frequency and percentage of individuals in each group who clinically improved, clinically stayed the same, and clinically worsened are reported.

Data were analyzed using IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp., Armonk, NY). Normality of data was determined using the Shapiro-Wilk test for all outcome data. All comparisons were two-tailed, and a significance level of less than .05 was considered to be statistically significant.

Results

The query of the EMR resulted in the identification of 7,385 potential participants, with 736 having NMR and PT and the other 1,006 having PT only. From this query 122, 61 in both treatment groups, participants were selected. Demographic descriptive data for the entire sample and by group can be found in Table 1. The median age of participants in this study was 58. (IQR = 14.0) years with the majority of the participants being male (80, 65.6%). All participants in the study had at least one comorbidity. The median number of days from PT evaluation to discharge was 98.5 (IQR = 61.0). The median number of visits which included NMR per case was 16.0 (IQR = 12.5). For standard PT, the median number of visits was 21.0 (IQR = 14.0). Seventy-eight (63.9%) participants were in the private payer category, 17 (13.9%) were in public payer category, and 27 (22.1%) were in the other payer category.

There was a statistically significant difference between treatment groups for seven of fourteen demographic variables (See Table 1). The treatment groups were found to be significantly different for payer type, age, number of comorbidities, number of total visits, number of PT visits, number of days between surgery and discharge, and number of days between evaluation and discharge. Post hoc analysis revealed that participants in the NMR treatment group had a significantly higher percentage of participants in the other category than those in the standard PT treatment compared to both private insurers (p = .001) and public insurers (p = .008).

Clinical Outcomes

Descriptive statistics and p values for analysis of differences between groups at the index assessment and the discharge assessment are given for all three clinical outcomes in Table 2. *P* values for differences between time periods within groups are given in Table 3. Change score results for all three clinical outcomes are presented in Table 4.

Active range of motion flexion. The difference between treatment groups at the index assessment and discharge assessment period were not significantly different for AROM flexion (See Table 2). However, both treatment groups improved significantly from the index assessment to the discharge assessment period (p < .001 for both groups). Analysis of change scores for each group indicates that the NMR group had significantly more change in AROM flexion than the standard PT group (p = .024).

Both treatment groups demonstrated clinical improvement in AROM flexion based on the established greater than or equal to 12 degree MDC value. However, significantly more participants in the NMR group had improvement in their AROM score greater than the established MDC compared to the standard PT group, $X^2(1, N = 122) = 7.65$, $p = .006$. Fifty-three (86.6%) participants in the NMR group demonstrated clinically meaningful change compared to 40 (65.6%) participants in the standard PT group. One participant (1.6%) in the standard PT group with clinically meaningful change actually worsened, and 21 participants (34%) stayed the same. Of the 86.6% of participants with clinically meaningful change in the NMR group, none worsened. Only eight participants (13%) in the NMR group clinically stayed the same. For both treatment groups, the improvement from the index assessment to the discharge assessment had a large effect size, $d = 1.34$ and $d = 1.56$ respectively. However, the difference in change scores had a relatively small effect size, $d = .42$.

Multiple regression analysis. Based on bivariate analysis, gender was found to be significantly different with AROM and was entered into the regression model along with treatment group. The regression model accounted for 5.4% of the variance of AROM flexion at the second time period. However, in the final model, gender was the only variable that significantly predicted AROM, $F(2,119) = 4.48$, $p = .013$, $R^2 = .054$, indicating that treatment group is not significantly associated with AROM.

Numeric Pain Rating Scale. The difference between treatment groups at the index assessment and discharge assessment period was not significantly different for pain (See Table 1). There was a statistically significant decrease in pain scores for both treatment groups from the index assessment to the discharge assessment period (See Table 3). However, the change scores for the treatment groups were not significantly different from each other (See Table 4).

Neither treatment group reached a level of clinical improvement in pain based on the established greater than or equal to 2.5 point MDC value. The two treatment groups were not statistically different for the greater than or equal to 2.5 point MDC value for NPRS change scores, $X^2(1, N = 118) = .32$, $p = .572$. In the standard PT group, three participants (4.9%) had at least a 2.5-point change; however, it was an increase in pain score. Twenty-three (40%) improved, and 31 (54.4%) stayed the same. In the NMR group, one participant (1.6%) clinically worsened, 30 (49.2%) improved, and 30 (49.2%) stayed the same. Even though it was not statistically significant, 9.2% more participants in the NMR group experienced clinically meaningful improvement in pain than in the standard PT group. Both treatment groups had large effect sizes for the analysis of differences between assessment periods for the NPRS, $d = .89$ and $d = 1.20$ respectively. The difference in change scores had a small effect size, $d = .29$.

Multiple regression analysis. Based on bivariate analysis, BMI was found to be significantly correlated with NPRS pain scores and was entered into the regression model along with treatment group. The regression model accounted for 9.3% of variance of pain scores at the second time period. However, only BMI significantly predicted pain at the discharge assessment, *F*(2,105) = 5.37, $p = .006$, $R^2 = .09$, indicating that treatment group was not associated with pain scores.

Disabilities of the Arm, Shoulder, and Hand. The difference between treatment groups at the index assessment and discharge assessment period were not significantly different for DASH (See Table 1). There was a statistically significant decrease in the DASH scores for both treatment groups from the index assessment to the discharge assessment period (See Table 3). The change in DASH scores from the index visit to the second time period for the standard PT group was slightly higher than the change for the NMR group, but the difference was not statistically significant. Mean, standard deviation (SD), and *p*-value for the DASH change scores are reported in Table 4.

Both treatment groups demonstrated clinical improvement in the DASH based on the established greater than or equal to 10.81 MDC value. However, there was no association between treatment groups and the greater than or equal to10.81 MDC cut off point for DASH change scores, $X^2(1, N = 50) = .00$, $p = .64$. None of the participants in either group clinically worsened, three (13%) in both groups stayed the same, and 20 (86.9%) in both groups improved. Both treatment groups had large effect sizes for analysis of differences between assessment periods, $d = 1.58$ and $d = 1.48$ respectively. However, the effect size for the difference between groups change scores was small, $d = .03$.

Multiple linear regression analysis. Based on bivariate analysis, the following variables were found to be significantly different or correlated with DASH: comorbidity number, BMI, FCI scores, comorbidity Y/N, and payer. Treatment group was entered into the regression model along with these variables to determine if they predicted DASH. The regression model accounted for 41% of the variance for DASH scores at the second time period. In the final model, the other payer category and comorbidity Y/N significantly predicted DASH at the second time period, $F(5, 39) = 5.35$, $p = .001$, $R^2 = .41$, indicating that there was no association between treatment group and the DASH.

Discussion

The purpose of this study was to determine if adding NMR to standard PT after rotator cuff repair, compared to standard PT alone, influenced clinical outcomes. The null hypothesis was that there would not be a statistically significant improvement in clinical outcomes when NMR was used in addition to standard PT compared to standard PT alone. The findings of this study were that both treatment groups significantly improved from index assessment to the discharge assessment period and the NMR group experienced a significantly greater statistical and clinical change in AROM flexion. However, the change in NPRS scores and the DASH as well as the difference between treatment groups at the second time period for all three clinical outcomes were not significantly different.

Active Range of Motion Flexion

The primary outcome of interest for this analysis was AROM shoulder flexion. There is extensive evidence in the literature that working to improve neuromuscular control of the rotator cuff and surrounding scapular musculature will reduce deleterious humeral head migration during active shoulder motion and enhance joint stability.[12,13,20-22,34,45,53,54] Authors have demonstrated that NMR exercises improve neuromuscular control.[13,20,21,45] Further, it has been reported that adding NMR to standard PT increases AROM shoulder flexion significantly more than standard PT alone in patients with impingement syndrome.[57] Our analysis discovered both treatment groups significantly improved from the index visit to the second time period. While the NMR group was not statistically significantly better than the standard PT group at the second time period, the NMR group demonstrated a statistically significantly greater change in flexion from the index visit to the second time period than the standard PT group (P=.024). While the effect size for this difference was small (d =.43),[81] this finding is still clinically relevant as can be explained by the following assessment of the data. When comparing the two groups for MDC cut-off scores, 86.6% individuals in the NMR group demonstrated clinically meaningful change compared to only 63.9% in the standard PT group. This indicated a greater number of individuals demonstrating clinically meaningful improvement in the NMR group than the standard PT group for shoulder AROM flexion. This finding refutes the primary hypothesis of this study that individuals who receive NMR will not demonstrate significant improvement in clinical outcomes compared to standard PT.

Active ROM flexion for both groups was comparable to the 165° average post-surgical follow up measure reported by Romeo et al[83] in a group sample of 72 patients who had full thickness rotator cuff tears. However, the length of time between surgery and post-surgical measurements in their study was 54 months,[83] comparing to the median length of time between surgery and the second time period in the present study is 98.5 days (3.5 months). Keener et al[37] reported a mean AROM flexion of 136° at three-month follow-up RCR surgery and 155° at six-month follow up. These values are significantly less than median values of 160° in the NMR group and 157° in the standard PT group for a similar follow up time period in this study. Both groups improved significantly greater in AROM in the first three months post operatively than was reported in the study by Keener et al.[37]

The statistically insignificant difference between treatment groups for AROM flexion at the second time period (p =.174) is similar to what Dilek at al[56] reported after NMR intervention in individuals with SIS. In that study, the authors reported a median of 170° in the NMR group and a median of 177° in the standard PT group after six weeks of intervention, summarizing that the groups were not significantly different (p = .72). Authors of that study reported a statistically significant change in flexion from baseline to six weeks in both treatment groups ($p < .016$) in both the NMR and standard PT group, similar to what was found in this current study after RCR (p = .001). While it may appear that adding NMR does not significantly improve AROM flexion greater than standard PT alone, Dilek et al[56] did not test for a difference in change scores between groups. They also reported that they did not conduct a sample size calculation prior to their study, which brought into question if their sample size of 61 participants could have contributed to a type II error in their results. Those authors reported the power of the study was 50% for proprioceptive changes at 12 months. The difference in median change scores between the NMR group and standard PT group in this study was both statistically significant and clinically significant, which means the magnitude of change in the NMR group was significantly greater than the standard PT group. Post hoc power analysis for AROM flexion revealed 73% power for analysis of AROM flexion in the current study.[70]

While it is relevant that there was a statistical and clinical difference between groups in AROM flexion, there was a confounding variable in the analysis that threatened the validity of results for this clinical measure. There was a statistically significant difference between genders for AROM flexion at discharge. Multiple linear regression revealed that gender significantly predicted AROM flexion, where the treatment group did not. However, demographic analysis looking for difference between treatment groups revealed the number of males and females were evenly distributed between treatment groups thereby reducing the overall effect gender might have had on statistical results. Additionally, the over-all sample was 65.6% males and 34.4% female, which is representative of the target population of individuals receiving RCR in the general population and therefore supports the external validity of results.[2,24,25]

Numeric Pain Rating Scale

Both treatment groups had a statistically significant improvement in pain from the index assessment to the discharge assessment ($p < .001$). However, pain levels were statistically similar between treatment groups at the discharge assessment, and there was no difference between groups in change scores ($p > .05$). Multiple regression analysis indicated that treatment group was not associated with pain scores. The NPRS results of this study are similar to what was reported after RCR for NPRS scores by Brennan et al.[25] Those authors reported a similar reduction in pain from pre to post rotator cuff repair rehabilitation on the NPRS from 4.1 to 2.0 in males and 4.9 to 2.5 in females ($p <. 05$). However, the finding of the current study that there was no difference between groups in pain scores or association between treatment group and pain scores at discharge, somewhat conflicts with what has been reported in the NMR literature for pain. Bae et al[57] reported a statistically significantly greater reduction in self-reported pain and function in the NMR group compared to the standard PT group ($p < .001$) for patients with SIS. Authors in that study were able to control better for the kind of exercises administered and progression for each treatment group. In this study, the assumption was made that NMR and standard PT interventions were representative of the current orthopedic literature and subject to the discretion of each physical therapist due to the retrospective nature of the analysis.

The MDC cut off point for the NPRS revealed that in the standard PT group 63.9% of individuals clinically did not change and only 40% clinically improved. Where in the NMR group only 49.2% clinically stayed the same and 49.2% clinically improved. While this difference was not statistically significant, 9.2% more individuals in the NMR group were found to demonstrate clinically meaningful improvement in pain than in the standard PT group. This difference, as well as the over-all statistically insignificant difference between groups, may have reached a level of statistical and clinical significance had it not been for missing data and an underpowered sample size. The post-hoc power analysis for the NPRS revealed the sample was only powered at 40%, which may have contributed to a type II error for these statistical test results.

Disability of the Arm Shoulder and Hand

Despite having such a large number of missing cases for DASH, it was decided to report results for the DASH after completing sub-analysis to determine if results from this sample population could be relevant to the broader RCR population. Published literature supports that including self-reported outcome measure results are significant to the overall validity of research.[25,56,57] The sub-analysis compared all the demographic variables between participants who had DASH data at the index assessment and discharge assessment and those who did not. The results of this analysis revealed that the two groups were not different for most of the variables. Therefore, participants with DASH data were determined to be demographically representative of the entire sample and were included in results. The DASH scores for both treatment groups improved significantly from pre to post intervention ($p < .001$), which is consistent with the DASH results in RCR rehabilitation literature.[25,26] However, no difference was found between groups at the second time period or between groups for change scores. Post hoc power analysis for DASH revealed the sample was only powered at 6%, which could have definitely contributed to a type II error. Concurrently, results may have been effected by whether individuals did or did not have comorbidities. There was a statistically significant difference in DASH scores between individuals that did have comorbidities and those that did not. Further, regression analysis revealed there was a significant association between the DASH scores at discharge and whether or not someone had comorbidities. However, the percentage of individuals who did and did not have comorbidities was not statistically different between treatment groups (p = .174). Finally, the median number of comorbidities and FCI score in the sample were each only one. However, the median of two comorbidities in the standard PT group was statistically significantly greater than the median of one in the NMR group (p = .047). Since these findings were somewhat conflicted as to extent comorbidities actually confounded the results of the analysis between treatment groups, a look at the literature on DASH scores in the RCR population and the effect of comorbidities on functional outcomes was conducted. Boissonnault et al[26] studied the impact of comorbidities on DASH outcomes in a sample of 118 individuals in the RCR population. They reported that DASH scores significantly improved pre rehabilitation to post rehabilitation, but having a greater number of comorbidities was not associated with poorer DASH scores post rehabilitation (p = .21). However, in another study, it was reported that a higher FCI score is statistically significantly associated with poorer functional outcome measures at the index visit and at 64 weeks in individuals with rotator cuff tear.[84] When those authors separated individuals that had RCR from individuals who managed the rotator cuff tear conservatively, they found that FCI scores were not statistically significantly associated with functional outcome change scores or functional outcomes at 64 weeks. Authors attributed this lack in association to an under-powered sample size. But they also reported that in their sample, for every 1-point change in FCI there was only a 3-point change in the functional outcome. Where they cited previous studies reported an MCID of 12-17 for that functional outcome which would have required an FCI of 3-5 comorbidities to reach a clinically relevant effect.[84] They concluded the lower mean FCI score of 1 might not be clinically relevant in predicting outcomes, where a much higher FCI score may result clinically meaningful change.[84]

Their results suggest that a lower FCI score (*Mdn* = 1.0) found in the current study was not likely to have effected change in DASH scores.

Conversely, the other payer category may have had a significant effect on DASH results at the second time period. As stated previously, payer type was associated with treatment groups. Post hoc chi square analysis revealed that the other category was the category most responsible for this association. There was a three to one ratio of other insurance in the NMR group compared to the standard PT group. Further, multiple regression revealed that predicted DASH scores were 14.2 points higher for those in the other category of payer than those that were not. Therefore, the other category of payer may have had an adverse effect on the NMR group DASH outcomes because the other category consisted of patients with worker's compensation and litigation cases which may have contributed to an underreporting of improvement in function with the DASH.

Limitations

There are multiple limitations of this study which must be considered when assessing the value of the findings of this study. Some of the limitations inherent to the retrospective nature of this analysis included inadequate control of exercise interventions given to each group and in particular the NMR group, standardization of data entry procedures for each participant, standardization of clinical measurements and self-reported outcomes, and missing participant outcome data.

One of the biggest limitations of this study was the assumption that the intervention exercises administered in the NMR treatment group were representative of the current best available evidence. Given the problems in the NMR literature with regard to exercise description and confusion with regard to definition of exercises, there was a possibility that the exercise interventions chosen by physical therapists and physical therapist assistants at ATI may have been an inconsistent representation of NMR exercises. This limitation may have also been influenced by possible discrepancies in CPT codes entered into the EMR by physical therapists and physical therapist assistants.

Due to the retrospective nature of this study, standardization of how CPT codes were entered was limited. There are no standard procedures for entering CPT codes within ATI Physical Therapy. The entry of CPT codes was dependent upon the therapists' working knowledge of neuromuscular re-education vs other therapeutic exercises presented in current orthopedic literature. The therapists understanding of proprioceptive and neuromuscular control deficits and which NMR exercises best train these deficits could have affected the effectiveness and timing of implementing these exercises thereby affecting the internal validity of the results. Other factors that may have affected validity could have been related to ways that data were entered into the EMR.

All initial data entry for the analysis, including comorbidities and outcome measures, was predicated on the completeness of the participants' reporting and the therapists' recording of the data. Therefore, it could not be guaranteed that the comorbidities reported were the complete comorbidities for each participant. Additionally, consistency and reliability of clinical measurement technique was dependent on the measurement of multiple clinicians.

While AROM flexion was done according to the industrywide standards for goniometric measurement, and ATI has some guidelines to improve reliability of clinical and self-reported outcome measures, there was still no way to adequately control proper patient positioning, mechanics, and alignment of the goniometer for measurement while assessments were taken. There were multiple measurers for clinical outcomes and self-reported outcome measures, which could have threatened the interrater reliability of results. However, interrater reliability was good to excellent for AROM, adequate for NPRS and, excellent for DASH, which would have mitigated the effect multiple measurers could have had on results. Further, due to the retrospective nature of this study, the therapists and patients could not have known about the significance of their results which helped control for rater bias or inflated measures. Also, because measurements were taken nationally, they are representative of the broader population of individuals having RCR increasing their external validity. Finally, missing DASH and NPRS data caused decrease in the sample size that decreased the statistical power for these measures, which may have statistically affected the results and caused a Type II error for these outcome measures.

Clinical Significance

Currently there does not appear to be a post-operative RCR rehabilitation approach superior to others.[32] This study explored if NMR exercises improved outcomes in the post-operative RCR population. In this study, both treatment groups demonstrated clinically meaningful change in all outcome measures. However, the magnitude of change in AROM was statistically and clinically better than the change experienced by the standard PT approach. This sample was demographically representative of the broader RCR population, so results may be generalized to this population. The NMR approach may provide the basis necessary to maximize improvement in shoulder motion after surgery. Further, there was a trend toward clinically improving results for pain as well.

Future Research

Authors may continue to improve defining NMR as a therapeutic exercise and how it may be effectively used in the post-operative RCR population and efficacy of NMR exercises.

Laboratory research is needed using RAP, RPP, and TTDPM to determine the extent of proprioceptive deficit after RCR. This would support the relevance of NMR in this population. Further, the current study would have been ideally conducted as a prospective study. A prospective study would better control for reliability of clinically measured and self-reported outcome measures. Precision and consistency of measurement could be better controlled for in a prospective study. Further, therapists should be given standard procedures and description of exercises for interventions chosen for NMR based on the current best available evidence. Ideally, such studies would use performance based tests of neuromuscular control, such the dynamic throwing performance index or the SADS test, and proprioceptive tests such a RAP, RPP, and TTDPM, along with clinical and self-reported outcome measures. Future studies would also need to control better for payer type.

Conclusion

This study explored if NMR improved outcomes after RCR surgery. Results showed that the null hypothesis, which stated NMR would not affect outcomes greater than standard PT, could not be entirely rejected. While significant differences in AROM flexion change scores were discovered between treatment groups and results were clinically significantly different, there was no difference between groups at the second time period. NPRS scores showed a trend toward being clinically significantly different with superior findings for the NMR group. However, both NPRS and DASH results may have been effected by confounding variables and an underpowered sample. Randomized controlled clinical research trials with standardized measurements and control for what is used for the NMR treatment approach is needed to further explore if NMR may be used to optimize outcomes in the post-RCR population.

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Table 1.

Demographic descriptive data

	Total (*N* = 122)	NMR PT (*N* = 61)	PT (*N* = 61)	
	N (%)	*N* (%)	*N* (%)	*p**
Gender: Male	80 (65.6)	37 (60.6)	43 (70.5)	.253
Female	42 (34.4)	24 (39.3)	18 (29.5)	
Payor				
Private	78 (63.9)	33 (54.0)	45 (73.7)	.005
Public	17 (13.9)	7 (11.5)	10 (16.4)	
Other	27 (22.1)	21 (17.2)	6 (9.8)	
Co-morbidity: Yes	83 (68)	38 (62.3)	45 (73.8)	.174
No	39 (32)	23 (37.8)	16 (26.2)	
Common Diagnosis				
Repair: RTC	75 (61.5)	41 (67.2)	34 (55.7)	.291
Repair: RTC, Type II or III	20 (16.9)	10 (16.4)	10 (16.4)	

Repair: Complete Rupture	27 (22.1)	10 (16.4)	17 (27.9)	
Surgical Side				
Right	76 (62.3)	37 (60.6)	45 (73.8)	.709
Left	46 (37.7)	24 (39.3)	16 (26.2)	
	Mdn (IQR)	*Mdn* (IQR)	*Mdn* (IQR)	
Age	58.5 (14)	55 (15)	60 (10.5)	.035
BMI	27.95 (5.8)	27.5 (6.6)	28.65 (5.7)	.206
FCI	1 (1)	1 (2)	1(1)	.189
Commorbidity Number	1 (3)	1 (1)	1 (1)	.047
Number of visits PT/case	21 (14)	18 (14.5)	25 (12.5)	.001
Number of visits total	20 (15)	16 (12.5)	25 (12.5)	.001
Surgery_Evaluation	25 (30.3)	24 (31.5)	26 (29)	.776
Surgery_Discharge	128 (58.5)	144 (58.5)	107 (42)	< .001
Evaluation_Discharge	98 (61)	121 (55)	86 (44)	< .001

Note. NMR = neuromuscular re-education, PT = physical therapy, IQR = interquartile range, BMI = body mass index, * $p < .05$.

Table 2.

Comparison of Outcomes Between Groups.

	Index Assessment			Discharge Assessment		
	NMR PT	PT		NMR PT	PT	
	Mdn (IQR)	*Mdn* (IQR)	*p**	*Mdn* (IQR)	*Mdn* (IQR)	*p*
AROM	125 (50.5)	130 (57)	.540	160 (19)	157 (36)	.177
NPRS	5 (3)	4 (2)	.051	3 (3)	2 (3)	.861
DASH	64 (25)	64 (34)	.490	21 (23.5)	22 (20.5)	.478

Notes. NMR = neuromuscular re-education. IQR = interquartile range. AROM = active range of motion for flexion. DASH = Disabilities of the Arm Shoulder and Hand questionnaire. NPRS = Numerical Pain Rating Scale. *$p < .05$

Table 3.

Comparison of Outcomes Within Groups

	NMR PT			Standard PT		
	Index	Discharge		Index	Discharge	
	Mdn (IQR)	*Mdn (IQR)*	*p**	*Mdn* (IQR)	*Mdn (IQR)*	*p*
AROM	125 (50.5)	160 (19)	< .001	130 (57)	157 (36)	< .001
NPRS	5.0 (3.0)	3.0 (3.0)	< .001	4.0 (2.0)	2.0 (3.0)	< .001
DASH	64 (25)	21 (23.5)	< .001	64 (34)	22 (20.5)	< .001

Notes. NMR = neuromuscular re-education. IQR = interquartile range. AROM = active range of motion for flexion. DASH = Disabilities of the Arm Shoulder and Hand questionnaire. NPRS = Numerical Pain Rating Scale. *$p < .05$.

Table 4.

Comparison of Change Scores for Outcomes Between Groups.

	NMR PT	Standard PT	
	Mdn (IQR)	*Mdn (IQR)*	*p*
AROM	30 (43.5)	23 (41.5)	.024*
NPRS	2.0 (3.0)	2.0 (3.0)	.123
DASH [a]	-34.88 (22.6)	-35.64 (23.6)	.908 [b]

Notes. NMR = neuromuscular re-education. AROM = active range of motion. NPRS = Numeric Pain Rating Scale. DASH = Disabilities of the Arm Shoulder and Hand questionnaire. [a] Mean and standard deviation values given. [b] Independent *t*-test results. *$p < .05$

Appendix A

Arthritis (rheumatoid and osteoarthritis)

Osteoporosis

Asthma

COPD, ARDS, or emphysema

Angina

Congestive heart failure (or heart disease)

Heart attack (myocardial infarct)

Neurological disease (such as multiple sclerosis or Parkinson's)

Stroke or TIA

Peripheral vascular disease

Diabetes (types I and II)

Upper gastrointestinal disease (ulcer, hernia, reflux)

Depression

Anxiety or panic disorders

Visual impairment (such as cataracts, glaucoma, macular degeneration)

Hearing Impairment (very hard of hearing, even with hearing aids)

Degenerative disc disease (back disease, spinal stenosis, or severe chronic back pain)

Obesity and/or BMI >30

Appendix B

ICD-9-CM code: 727.61

ICD-10-CM codes:

M25.511,

M25.512,

M75.41,

M75.42,

S46.011D,

S46.012D,

Z47.89

Appendix C

Current Procedural Technology (CPT) codes:

97001,

97010,

97014,

97016,

97035,

97110,

97140,

97530,

97530.59