Open Access Journal of Sports Medicine

Dovepress
open access to scientific and medical research

Open Access Full Text Article

REVIEW

Optimal management of shoulder impingement syndrome

This article was published in the following Dove Press journal:
Open Access Journal of Sports Medicine
28 February 2014

Rafael F Escamilla[1,2]
Todd R Hooks[3]
Kevin E Wilk[4]

[1]Department of Physical Therapy, California State University, Sacramento, CA, USA; [2]Andrews Research and Education Institute, Gulf Breeze, FL, USA; [3]Drayer Physical Therapy Institute, Columbus, MS, USA; [4]Champion Sports Medicine, Birmingham, AL, USA

Abstract: Shoulder impingement is a progressive orthopedic condition that occurs as a result of altered biomechanics and/or structural abnormalities. An effective nonoperative treatment for impingement syndrome is aimed at addressing the underlying causative factor or factors that are identified after a complete and thorough evaluation. The clinician devises an effective rehabilitation program to regain full glenohumeral range of motion, reestablish dynamic rotator cuff stability, and implement a progression of resistive exercises to fully restore strength and local muscular endurance in the rotator cuff and scapular stabilizers. The clinician can introduce stresses and forces via sport-specific drills and functional activities to allow a return to activity.

Keywords: rotator cuff impingement, internal impingement, overhead athlete, shoulder, rehabilitation

Introduction

Shoulder impingement has two distinct pathological conditions: subacromial and internal impingement. Impingement syndrome, used to describe subacromial impingement, was coined by Charles Neer in 1972.[1] The supraspinatus tendon, via its insertion onto the greater tuberosity, the subacromial bursa, and the long biceps tendon as it passes through the bicipital groove, is positioned anterior to the coracoacromial arch (lateral acromion and coracoacromial ligament), and with shoulder flexion in the neutral position, these structures must pass under this arch and are susceptible to impingement.[1] Neer described this as a progressive syndrome with three stages, beginning with chronic bursitis and proceeding to partial and complete tears of the supraspinatus tendon, which may extend to rupture of other parts of the rotator cuff and may also involve the long biceps tendon. Since this original description of subacromial impingement, Matsen and Artnz[2] have further defined impingement as the encroachment of the acromion, coracoacromial ligament, coracoid process, or acromioclavicular joint on the rotator cuff mechanism and bursa that passes beneath them as the glenohumeral joint is moved, particularly in flexion and internal rotation (IR).

In contrast, internal impingement, which involves impingement between the posterosuperior labrum and undersurface of the supraspinatus and infraspinatus tendons, typically occurs in overhead athletes when the arm is abducted and externally rotated. In the presence of anterior capsular laxity, the humeral head tends to excessively glide anterior, causing impingement of the supraspinatus and infraspinatus on the posterosuperior edge of the glenoid rim, which leads to undersurface rotator cuff tears and fraying of the posterosuperior glenoid labrum.[3,4] The focus of this article is

Correspondence: Rafael F Escamilla
Department of Physical Therapy,
California State University, 6000 J St,
Sacramento, CA 95819-6096, USA
Tel +1 916 278 6930
Email rescamil@csus.edu

submit your manuscript | www.dovepress.com
Dovepress
http://dx.doi.org/10.2147/OAJSM.S36646

the subacromial impingement and the optimal treatment of this pathology.

Neer described three stages of the impingement syndrome.[5] In stage 1, a reversible edema and hemorrhage is present in a patient that is typically younger than 25 years. These patients present with an aching discomfort caused by inflammation of the supraspinatus tendon and long head of the biceps brachii. Stage 2 is usually seen in patients aged 25–40 years and involves fibrotic changes in the supraspinatus tendon and subacromial bursa that cause pain with activity. Stage 3 typically occurs in individuals older than 40 years with an extended history of shoulder pain, osteophyte formation, and either a partial- or full-thickness rotator cuff tear.

Although rotator cuff pathology is well described in the literature in overhead athletes such as baseball players and swimmers, Neer[5] reported that 70% of rotator cuff tears occur in sedentary individuals. This condition is progressive in nature and is perpetuated by the continued passages of the rotator cuff under the coracoacromial arch. This continued irritation can result in enlargement of the subacromial bursa, which can become fibrotic and further diminish the subacromial space. Continued irritation can create microtears and partial-thickness rotator cuff tears, leading to osteophyte formation and complete rotator cuff tears.

The subacromial space is bordered superiorly by the acromion, acromioclavicular joint, and coracoacromial ligament and measures approximately 5–10 mm from the humeral head.[6] Thus, during arm elevation, some degree of rotator cuff impingement may occur; it is most susceptible to occurring at 90° of abduction when the scapula has not rotated upward adequately to ensure the rotator cuff does not impinge on the acromion and coracoacromial ligament.[6–8] Humeral rotation also influences impingement during forward flexion, as during IR, the greater tubercle encroaches on the acromion, the coracoacromial ligament, and possibly the coracoid process; however, if the humerus is externally rotated, the greater tubercle is rotated from the acromial arch and can be elevated without impingement.[9] Impingement can also occur during horizontal adduction as the head of the humerus approximates on the coracoid process.[1]

Causative factors

Rotator cuff pathology can be divided into classifications on the basis of the pathology and pathomechanics of injury (Table 1). Subacromial impingement can occur through a variety of mechanisms and can be a result of either structural and/or functional contributing factors (Tables 2 and 3).

Table 1 Classification of rotator cuff pathologies

Pathology
Primary compressive disease
Instability with secondary compressive disease
Primary tensile overload
Tensile overload because of capsule instability
Rotator cuff tear
Primary internal impingement
Calcific tendinitis
Partial articular-sided tendon avulsion lesion
Partial articular tear with intratendinous extension lesion
Secondary internal impingement with primary hypermobility
Secondary tensile overload with primary hypermobility

There are numerous potential functional causes of subacromial impingement. Capsular mobility impairments, either hypomobility or hypermobility, have been reported to contribute to impingement. Increased laxity of the glenohumeral capsule may limit the ability of the capsule to restrain the accessory motions of the humeral head during active movements, thereby causing impingement.[3,4] Harryman et al[10] demonstrated excessive humeral head superior migration in the presence of posterior capsule tightness. Abnormal scapula position has been described as a source of glenohumeral dysfunction.[11–15] Abnormal scapula motion that occurs during active movements is referred to as scapular dyskinesis and can predispose the patient to shoulder impingement.[12] Postural deviations (such as scoliosis or rounded shoulder posture) can influence both thoracic and cervical spine orientation and both resting and dynamic scapula position. Last, an

Table 2 Structural factors contributing to impingement syndrome

Factors
Bursae
Inflammation
Thickening
Rotator cuff tendon
Tendinitis
Thickening
Partial-thickness tears
Humeral head
Congenital abnormalities
Fracture malunion
Acromioclavicular joint
Joint abnormalities
Sprains
Degenerative spurs
Acromion
Abnormal shape
Spurs
Os acromiale, unfused
Malunion of fracture
Nonunion of fracture

Table 3 Functional factors contributing to impingement syndrome

Factors
Rotator cuff
Weakness
Inflammation
Imbalance
Poor dynamic stabilization
Capsular
Hypomobility
Hypermobility
Scapular factors
Postural adaptations
Position
Restriction in motion
Neuromuscular control
Paralysis
Facioscapulohumeral muscular dystrophy

inefficient rotator cuff can predispose an individual to rotator cuff impingement. The primary function of the rotator cuff is to stabilize the humeral head and maintain its position in the central aspect of the glenoid fossa. However, if weakness is present in the rotator cuff, contraction of the deltoid (primarily at lower abduction angles between 0° and 45°) will create a superior shear of the humeral head, causing impingement against the coracoacromial arch. To allow for an effective and efficient treatment, the rehabilitation specialist should determine the causative factor or factors contributing to the impingement syndrome to effectively treat the condition and not just eliminate the symptoms.

Clinically, the patient can present with multiple causative factors that accumulate to attribute to their pathology. Matsen and Arntz[2] described rotator cuff impingement as a self-perpetuating process, noting the following: muscle or cuff tendon weakness causes impingement as a result of diminished stabilization of the humeral head, which contributes to tendon damage, disuse atrophy, and additional cuff weakness; bursal thickening causes impingement as a result of narrowing the subacromial space; and posterior capsule tightness develops, perpetuating the impingement syndrome.

The supraspinatus tendon is the structure most likely to be involved in impingement syndrome. The diminished vascularity of the tendon has long been proposed to be a contributing factor in the development of subacromial impingement. Codman first observed a hypovascular "critical zone" just proximal to the insertion of the supraspinatus tendon in 1934.[16] However, further studies have shown significant blood flow in the critical zone that is no more avascular than other parts of the rotator cuff;[17,18] it is, rather, a zone of anastomoses between the osseous vessels (anterior and posterior humeral circumflex) and tendinous vessels (suprascapular and subscapular). Although it now is accepted that the rotator cuff is not avascular, it has been reported that the blood flow is dependent on arm position. Rathbun and Macnab[19] reported a wringing out of the supraspinatus with the shoulder in an adducted position, whereas Sigholm et al[20] have shown a reduction in tendon microcirculation as a result of increased subacromial pressure from 8 to 56 mmHg that occurs during active forward flexion to 45° with a 1 kg weight. Even though arm positioning has shown diminished vascularity, because the shoulder is frequently moved, it is not clear whether either of these movements could produce sufficient ischemia.[2] In addition, it has also been reported that the vascularity to the rotator cuff diminishes with age.[21]

Changes in coracoacromial arch structure have been shown to be predictive in the presence of impingement syndrome.[1,22] Studies have identified three shapes of the acromion (type 1, smooth; type 2, curved; and type 3, hooked), and it has been reported that an increased likelihood (70% of the cases) of rotator cuff lesions occur in the presence of a hooked acromion.[1,22] However, it cannot be determined whether the acromial shape is caused by or results from a cuff tear.[2,23]

Nonoperative management

Steroid injections have long been used in the treatment of tendinopathies. However, they may contribute to tendon atrophy and cause cellular necrosis and reduce the ability of the damaged tendon to heal.[2,24] In addition, studies have shown minimal effectiveness when steroid injections are used in isolation.[25,26] The vascularity of the rotator cuff and its influence on the tissues' ability to heal are a point of discussion that have led health care professionals to seek alternate ways of augmenting the healing process. Platelet-rich plasma (PRP) is an enriched platelet blood plasma that contains growth factors and other cytokines that stimulate and enhance the body's own healing response. PRP injections are prepared using an autologous blood sample that is centrifuged twice to allow extraction of the PRP that is injected directly into the tendon. Although PRP injections are commonly performed for tendinopathies, a systematic review of the literature by Foster et al reported few controlled clinical trials that have adequately evaluated the safety and efficacy of treatments and concluded PRP to be a promising, but not proven, treatment option for tendon and muscle injuries.[27] The Focused Aspiration of Soft Tissue procedure (FAST) has recently gained attention in the treatment of tendon pathology by its ability to ablate diseased tissue. An ultrasound-guided needle is placed on a hypoechoic identified region of the tendon as the tissue is debrided, emulsified, and aspirated. This technique affords a quicker recovery time, with patients able to typically return to prior level of function in 4–8 weeks.

Nonoperative rehabilitation

Nonoperative rehabilitation programs for impingement syndrome have been reported in the literature, consisting of rest, rotator cuff and scapula strengthening, and manual techniques, with good outcomes.[28–34] Conroy and Hayes[29] demonstrated that after 3 weeks of treatment, participants receiving both exercises and manual therapy had less pain compared with participants who performed exercises only. Bang and Deyle[28] reported on the outcomes of patients who performed strengthening and stretching compared with those who performed the same exercise program and received manual therapy to the cervical and thoracic spine and shoulder joint after 3–4 weeks of treatment. Subjects who received manual therapy plus stretches reported less pain and improved function and strength compared with the stretch-only group. Before the initiation of the therapy program, it is imperative to perform a complete and thorough evaluation. This will enable the clinician to establish an accurate diagnosis, identify all causative factors, and determine the involved structure or structures. This will allow the rehabilitation specialist to implement an individualized treatment program to address these factors and prioritize the treatment goals. The primary emphasis of the treatment program is to reduce the mechanical irritation to the rotator cuff and promote a restoration in tendon vascularity that can result from muscle guarding, mechanical compression, and abnormal shoulder mechanics.

The nonoperative rehabilitation program outlined in this article for the treatment of shoulder impingement is a multiphased approach focused on a return to prior level of function via a systematic process. This treatment program is outlined in Table 4 and consists of four phases that are a gradual progression of exercises and implied stresses that increase and become more demanding than those of the previous phase of treatment. The effectiveness of the treatment program is based on the identification of the underlying causative factor or factors and the individualized program designed to address this condition.

Phase 1: acute phase

The goals in this phase are to normalize motion, diminish pain and inflammation, reestablish baseline dynamic stability, correct postural adaptations, and educate the patient in activity

Table 4 Nonoperative treatment of subacromial impingement rehabilitation protocol

Phases
Maximal protection: acute phase
Goals
Relieve pain and inflammation
Normalize range of motion
Reestablish muscular balance
Improve posture
Patient education and avoidance of aggravating activities
Avoidance
Elimination of any activity that causes an increase in symptoms
Range of motion
L-Bar
Flexion
Elevation in scapular plane
External and internal rotation in scapular plane at 45° abduction
Progress to 90° abduction
Horizontal abduction/adduction
Pendulum exercises
Active-assisted range of motion: limited symptom-free available range of motion
Rope and pulley
Flexion
Joint mobilizations
Inferior and posterior glides to the GH joint in the scapular plane
Goal is to establish balance in the glenohumeral joint capsule
Modalities
Cryotherapy
Iontophoresis
Laser
Strengthening exercises
Rhythmic stabilization exercises for ER/internal rotation
Rhythmic stabilization drills Flex/ext
External rotation strengthening
If painful, isometrics (ER, internal rotation, Abd)
Scapular strengthening
Retractors
Depressors
Protractors
Postural exercises
Strengthen scapular muscles (depressors, retractors, and protractors)
Stretch pectoralis minor (corner stretch)
Wall circles
Patient education
Educate patient regarding activity level, activities
Pathology and avoidance of overhead activity, reaching, and lifting activity
Correct seating posture (consider lumbar roll)
Seated posture with shoulder retraction, scapular ER, posterior tilting
Consider postural shirt for patients with poor posture
Guideline for progression
Decreased pain and/or symptoms
Normal range of motion
Elimination of painful arc
Muscular balance

(*Continued*)

Table 4 (*Continued*)

Intermediate phase
Goals
Reestablish nonpainful range of motion
Normalize arthrokinematics of shoulder complex
Normalize muscular strength
Maintain reduced inflammation and pain
Increase activities with involved arm
Range of motion
L-Bar
Flexion
External rotation at 90° of abduction
Internal rotation at 90° of abduction
Horizontal abduction/adduction at 90°
Rope and pulley
Flexion
Joint mobilization
Continue joint mobilization techniques to the tight aspect of the shoulder (especially inferior)
Initiate self-capsular stretching
Grades 2, 3, 4
Inferior, anterior, and posterior glides
Combined glides as required
Modalities (as needed)
Cryotherapy
Ultrasound/phonophoresis
Iontophoresis
Postural exercises
Continue with stretching of pectoralis minor and strengthening scapular muscles
Continue use of postural shirt
Strengthening exercises
Progress to complete shoulder exercise program
Emphasize rotator cuff and scapular muscular training
ER tubing
Sidelying ER
Full can
Shoulder abduction
Prone horizontal abduction
Prone shoulder extension
Prone rowing
Prone horizontal abduction ER
Biceps/triceps
Lower trapezius muscular strengthening
Scapular neuromuscular exercises
Functional activities
Gradually allow an increase in functional activities
No prolonged overhead activities
No lifting activities overhead
Advanced strengthening phase
Goals
Improve muscular strength and endurance
Maintain flexibility and range of motion
Maintain postural correction
Gradual increase in functional activity level
Flexibility and stretching
Continue all stretching and range-of-motion exercises
L-Bar: ER/internal rotation at 90° abduction
Continue capsular stretch
Maintain/increase posterior/inferior flexibility

(*Continued*)

Table 4 (*Continued*)

Strengthening exercises
Establish patient on the fundamental shoulder exercises
Tubing ER/internal rotation
Lateral raises to 90° dumbbell
Full can dumbbell to 90°
Sidelying ER
Prone horizontal abduction
Prone extension
Wall slides
Biceps/triceps
Scapular neuromuscular control drills
Guideline for progression to phase 4
Full, nonpainful range of motion
No pain or tenderness
Strength test fulfills criteria
Satisfactory clinical examination
Return to activity phase
Goals
Unrestricted, symptom-free activity
Initiate interval sport program
Throwing
Tennis
Golf
Maintenance exercise program
Flexibility exercises
L-Bar
Flexion
External rotation and internal rotation at 90° abduction
Self-capsular stretches
Isotonic exercises
Fundamental shoulder exercises
Perform three times a week

Abbreviations: ER, external rotation; GH, glenohumeral; Abd, abduction; Flex/ext, flexion/extension.

modification and avoidance. One of the primary goals in this phase is to diminish the patient's pain and inflammation. Initially, the patient should be educated about modification and avoidance of activities (such as overhead sports and exercises) and postural awareness with sitting and standing positions to increase subacromial space.

Clinically, pain and inflammation can be diminished through the use of local therapeutic modalities such as ice, ultrasound, electrical stimulation, and iontophoresis.

Cryotherapy serves as a vasoconstrictor to reduce the metabolic activity, thereby diminishing inflammation.[35,36] Cryotherapy also increases the pain threshold, allowing for decreased pain associated with an acute injury and allowing the facilitation of normal shoulder motion.[37–39] Once the acute inflammatory stage has abated, the clinician may implement the use of moist heat, warm whirlpool, and/or ultrasound to prepare the soft tissue for range of motion and mobilizations to improve extensibility of the capsule and musculotendinous tissues. In the early phases of treatment, grade 1 and 2 mobilizations can be performed to neuromodulate pain via the stimulation of type 1 and type 2 mechanoreceptors.[40,41] The patient is instructed to perform frequent bouts of active-assisted range of motion (AAROM) and stretching exercises, as this has been shown to reduce pain.[42] Stackhouse et al[43] documented a 32% decrease in external rotation (ER) force production and a 23% decrease in electromyography (EMG) activity in a painful shoulder. This further illustrates the importance of diminishing pain to allow for normal recruitment of the rotator cuff muscles.

The patient may have a decrease in active range of motion (ROM) with either a spasm or painful end feel on initial presentation. The patient should be educated to avoid/minimize activities in which the arm is raised above shoulder height to avoid motions that create impingement.[6] The patient is also instructed to refrain from resting the arm at the side, instead having the shoulder supported slightly away from his or her side to allow for increased vascularity to the healing structures.[20,30]

During the acute phase of rehabilitation, it is important for the clinician to normalize motion. This is achieved through the use of AAROM, passive ROM exercises, and manual techniques. Wilk and Andrews[44] described a reverse capsular pattern in patients with subacromial impingement in which IR is most limited, followed by abduction, and then ER. This can be caused by inferior and/or possibly posterior capsular tightness. The clinician should direct the treatment toward clinical findings, using a combination of joint mobilizations, specific stretching activities, and AAROM exercises to restore shoulder ROM. The authors commonly prescribe AAROM, using a T-bar for overhead flexion and external rotation performed at both 45° and 90° of shoulder abduction. The patient is instructed to perform overhead flexion, with the arm maintained in an externally rotated position throughout the movement to minimize the impingement of the greater tuberosity on the acromion.

Self stretches and manual flexibility exercises are also incorporated into the treatment program. Although the clinician should assess the flexibility of the surrounding musculature of the shoulder, we commonly prescribe stretches for the anterior shoulder and chest for the general orthopedic population, whereas we commonly prescribe stretches for the posterior shoulder for overhead athletes. Borstad and Ludewig[45] compared three stretching techniques (unilateral self stretch, supine manual stretch, and seated manual stretch) and demonstrated the unilateral self stretch to be most effective. Muraki et al[46] using cadaveric specimens, have reported that the most effective stretch for the pectoralis minor is performed with scapular retraction at 30° of shoulder flexion. Clinically, the authors prescribe both stretches while using the following considerations when prescribing pectoralis minor stretches: monitoring the patient's ability to relax, adding humeral abduction and ER, and positioning the scapula in an ER and posteriorly tilted position can maximize the stretching imposed on the pectoralis minor.[45] The posterior shoulder is subject to repetitive eccentric contractions with throwing that can result in soft tissue adaptations of the posterior rotator cuff; therefore, flexibility exercises are commonly prescribed for the overhead athlete.[47] A modified cross-body horizontal adduction and modified sleeper stretch are performed for the posterior shoulder musculature.

The scapula plays an important role in normal upper extremity function; therefore, proper mobility and stability are essential for asymptomatic activity. Scapula position has been shown to contribute to subacromial impingement and should therefore be assessed to determine resting position and mobility.[48] A common postural presentation in both sedentary individuals and overhead athletes is a rounded shoulder and forward head position. Using dynamic magnetic resonance imaging, Solem-Bertoft et al[49] demonstrated that the subacromial space decreased as the shoulder moved from a retracted to a protracted position. Anteriorly, this scapula position is associated with decreased flexibility or adaptive shortening of the pectoralis minor. This decreased flexibility not only can affect scapula position but also can cause occlusion of the axillary artery, causing neurovascular symptoms.[50,51] Posteriorly, this postural presentation can contribute to stretch weakness of the posterior scapular musculature, particularly the rhomboid muscles and lower trapezius because of prolonged elongation. Lukasiewicz et al[48] reported that patients who have subacromial impingement, when compared with those who do not, display less posterior scapular tilting during arm elevation. Manual positioning of the scapula has been shown to increase strength of the supraspinatus as well as increase the subacromial space in patients with subacromial impingement.[52,53] Clinically, the authors also use manual scapular assistance to provide tactile cueing for scapula positioning as a means of identifying potential patients for whom subacromial space is a contributing factor. Postural cueing for scapular positioning can also be provided using shirts designed to give tactile stimulation for optimal positioning. These shirts can be worn during a rehabilitation program and/or during activities of daily living (ADLs).

Strengthening exercises are initiated in the early phase of rehabilitation with the primary intent of restoring muscle balance/ratios and retarding muscle atrophy.[54,55] In the presence of excessive pain or soreness, isometric exercises may be warranted in the acute phases of rehabilitation and can be progressed to isotonics when appropriate. Isometrics can be performed at multiple angles throughout the pain-free available ROM. Initially, the intent of these exercises is to reestablish dynamic stability; as a consequence, the rehabilitation specialist should focus on strengthening the inherently weak posterior rotator cuff and supraspinatus.[54,55] In addition, exercises for the trapezius, serratus anterior, and rhomboid muscles are performed to regain scapular stability. Manual rhythmic stabilization exercises are performed, beginning with the internal and external rotators, with the arm in the scapular plane at 30° of shoulder abduction. A co-contraction of the internal and external rotators is facilitated via alternating manual input requiring an isometric stabilization of the patient. These stabilization drills can be additionally performed with the arm held at approximately 100° of elevation and 10° of horizontal abduction. This "balanced position" is an advantageous initiation point because of the combined centralized resultant force vectors of both the rotator cuff and deltoid musculature that generates humeral head compression.[56,57] The clinician can begin to implement other planes of external stimulus to facilitate recruitment of the surrounding musculature as well as place the arm at various angles of both elevation and external rotation.

As a result of macro- or microtrauma, proprioceptive awareness can be diminished; therefore, the clinician should perform drills to restore the neurosensory properties of the joint capsule to heighten the sensory awareness of the afferent mechanoreceptors early in the rehabilitation program.[58,59] Improved proprioception has been shown after neuromuscular training drills that challenge the glenohumeral musculature.[60] Padua et al reported seeing a significant improvement in shoulder function and enhanced functional throwing performance test scores after a 5-week training session using proprioceptive neuromuscular facilitation (PNF) drills.[61] Initially, rhythmic stabilization drills for the internal and external rotator cuff muscles are implemented and PNF patterns are performed while incorporating rhythmic stabilization and slow reversal hold to enhance proprioception and dynamic stability.[54,55,58,59,62,63] These exercises are performed to facilitate coactivation of agonist/antagonist muscle groups to enhance joint congruency and compression by restoring balance of the force couples of the shoulder joint.[64] In addition, joint reproduction drills and axial loading exercises (upper extremity weight bearing) can be performed in the early stages of treatment. Weight-bearing exercises such as weight shifts, weight shifting on a ball, wall push-ups, and quadruped positioning serve to stimulate the articular mechanoreceptors and assist in restoring proprioception.[55,65,66]

Phase 2: intermediate phase

The goals of phase 2 of the rehabilitation program are to progress the strengthening program; continue to improve flexibility, mobility, and ROM of the shoulder joint complex; and enhance neuromuscular control. The criteria to allow progression into phase 2 are decreased signs of inflammation, no warmth noted with palpation, and overall good tolerance of stage 1 exercises. Strengthening exercises are progressed in this phase to more aggressive isotonics aimed at restoring balanced muscle force coupled by performing isolation exercises of selective muscles. Wilk et al[65] have developed an exercise program, referred to as the Thrower's Ten Program, that is based on a collection of EMG data from numerous investigators.[18,67–75] The external rotators frequently exhibit weakness and are therefore a common muscle group to emphasize during rehabilitation. Sidelying (lying on side) shoulder ER and prone rowing with shoulder ER have been shown to elicit high posterior cuff EMG activity and are therefore commonly prescribed exercises.[69]

Neuromuscular drills performed during phase 1 can be progressed to include stabilizations at end range of motion. PNF exercises are now performed in a full arc of the patient's available range of motion that also includes the addition of rhythmic stabilization drills in various degrees of elevation during this exercise. This serves to promote dynamic stabilization and endurance training of the rotator cuff. Manual resistance training can also be included in this phase of training. This allows the rehabilitation specialist the opportunity to vary the resistance during the movement, easily incorporate and interchange concentric and eccentric activity, add manual cueing and/or isometric stabilizations for the scapular musculature, and perform rhythmic stabilizations during the exercise.

Exercises targeted to isolate the supraspinatus such as the "empty can exercise" are commonly prescribed with the arm maintained in full IR (thumb down) while elevation is performed in the scapular plane.[76] This exercise gained popularity based on the report by Jobe and Moynes[76] of high levels of EMG activity in the supraspinatus muscle with this movement. Since this original description of the EMG activity of the supraspinatus, several investigators have explored the efficiency of this movement, as well as the optimal movement to effectively isolate the supraspinatus. Townsend et al[74] reported that the best exercise to activate the supraspinatus muscle was the military press; however, the authors do not commonly prescribe this exercise in overhead athletes. Blackburn et al[67] initially reported that having a patient lying prone with the arm abducted to 100° and full external rotation produced the highest EMG activity in the supraspinatus compared with the empty can exercise. This was later substantiated by Malanga et al.[77]

Clinically, we have noted that when patients perform the empty can exercise, a feeling of pain or discomfort is often reported. The authors believe this may be a result of weakness of the external rotator cuff muscles unable to prevent superior translation or displacement of the humeral head. External rotation weakness has been reported in overhead throwing athletes;[78] therefore, we advocate the "full can" exercise as a means to avoid the potential impingement created as the humeral head is displaced superiorly during the empty can maneuver.

The scapula serves to provide proximal stability to allow for efficient distal segment mobility and is vital for normal proper arm function. The significance of scapular muscle strength and neuromuscular control to allow for normal shoulder function has been well described by numerous authors.[13–15,79] Cools et al,[80] using surface EMG, noted significant slower muscle activation in the middle and lower trapezius and muscle latency in patients with shoulder impingement. Wilk and Arrigo[55] devised specific exercises designed to normalize the muscular force couples of the scapulothoracic joint and, in addition, stimulate the proprioceptive and kinesthetic awareness to enhance the neuromuscular control of the scapulothoracic joint. The scapular retractors, protractors, and depressors are commonly emphasized with isolation strengthening exercises because of weakness commonly noted. Neuromuscular control and PNF drills can be incorporated into the exercise regimen for the scapula.

Closed kinetic chain exercises are progressed by incorporating proprioceptive drills. Weight shifting drills are advanced to include a table push-up on a ball or an unstable surface. In overhead throwing athletes with impingement, performing a push-up exercise on an unstable or modified surface has been shown to generate more upper trapezius, middle trapezius, and serratus anterior activity compared with performing the standard push-up exercise.[81] Wall stabilizations are performed as the patient's hand is on a small ball and as the clinician performs perturbation drills to the patient's arm.

Flexibility exercises for the shoulder are continued throughout phase 2, and stretching activities for the trunk musculature are incorporated into the rehabilitation program. In addition, during the second phase of rehabilitation, stabilization and strengthening exercises for the abdomen and lower back region are initiated. Athletes are encouraged to perform lower extremity strengthening and conditioning activities specific for their sport.

Phase 3: advanced strengthening phase

The goals during phase 3 are to initiate aggressive strengthening drills, augment power and endurance, progress functional drills, and initiate sport-specific drills such as throwing activities. The criteria for initiating phase 3 include normal shoulder ROM, symptom-free ADLs, and an increase in muscle strength. This phase is intended to continue to build on the prior two phases, as the patient will continue to perform the Thrower's Ten exercises and manual resistance stabilization drills as plyometric activities are implemented into the rehabilitation program. Full-shoulder ROM and flexibility should be maintained throughout this phase and the remainder of the rehabilitation program. Dynamic stabilization drills such as rhythm stabilization performed in a functional position, push-ups on a ball, and ball throws are performed to improve proprioception and neuromuscular control.

Plyometrics can be initiated during this phase of rehabilitation and are meant to further enhance dynamic stability and proprioception as well as introduce and gradually increase functional stresses on the shoulder joint. After a 6-week plyometric training program, Swanik et al[82] reported an enhanced joint position sense and kinesthesis and a decreased time to peak torque generation with isokinetic testing. Fortun et al[83] compared 8 weeks of plyometric training with conventional isotonic training and reported an increased shoulder IR power and throwing distance. Plyometrics can be divided into three phases that use both the elastic and reactive properties of muscles and connective tissues to generate maximum force production.[84–86]

Plyometrics begin with a rapid prestretch eccentric muscle contraction that stimulates the muscle spindle. The amortization phase, which is the time between the eccentric and concentric phases, occurs next. The time spent in this phase should be as short as possible to allow for a transfer of energy and prevent the beneficial neurologic effects of the prestretch from being dissipated as heat. The final phase is the resultant concentric contraction. A plyometric exercise program has been described by Wilk et al,[87,88] consisting of a systematic progression of drills designed to gradually introduce stresses on the healing tissues. The athlete is instructed to incorporate the trunk and lower extremity to allow a transfer of energy into the upper extremity during the plyometric drills. The plyometric program will begin with two-handed drills such as a chest pass, side-to-side throws, side throws, and overhead soccer throws. Once these two-handed exercises drills can be efficiently performed, the athlete is progressed to one-handed drills, including standing one-handed throws in a functional throwing position, wall dribbles, and plyometric step and throws. Other techniques designed to enhance training, coordination, and the transfer of kinetic energy include throwing an underweighted or overweighted ball (ball that is either less than or more than the weight of an official baseball).[86,89–93] The underweighted ball is most commonly used to improve the transfer of energy and angular momentum, whereas the overweighted ball is used to enhance shoulder strength and power.[83,90,91,93]

The ill effects of muscle fatigue on proprioceptive sense and altered biomechanics have been reported; as a result, muscle endurance training should also be introduced into the rehabilitation program for overhead athletes. Murray et al,[94] using kinematic and kinetic motion analysis, noted that once a thrower was fatigued, shoulder external rotation decreased and ball velocity diminished, as did lead knee flexion and shoulder adduction torque. Voight et al[95] reported a relationship between muscle fatigue and a decrease in shoulder proprioception. On the initiation of arm elevation, the humeral head has been shown to migrate superiorly when the rotator cuff muscles are fatigued.[96] In addition, Lyman et al[97] documented that complaints of muscle fatigue in Little League pitchers had the greatest predisposing factor to risk for shoulder injuries. Specific endurance exercises that are commonly used by the authors include wall dribbling with a Plyoball (Functional Integrated Technologies, Watsonville, CA, USA), wall arm circles, upper body cycle, and isotonic exercises using lower weights with higher repetitions.

An interval throwing program (ITP) can be implemented during the third phase of rehabilitation. The ITP is designed to gradually increase the quantity, distance, intensity, and type of throws needed to facilitate the restoration of normal throwing biomechanics. Before the initiation of this program, it may be beneficial to have the athlete perform "shadow" or "mirror" throwing, which allows the athlete to work on proper throwing mechanics before actually throwing a baseball. The interval throwing program can be instituted once the athlete can fulfill the following criteria: satisfactory clinical examination; full, nonpainful range of motion; satisfactory isokinetic test results; and successful completion of an appropriate rehabilitation program.

The ITP is organized into two phases: phase 1 is a long-toss program (45–180 feet [15–60 m]), and phase 2 is a mound throwing program used for pitchers.[34] ITP phase 1 is commonly initiated at 45 feet (15 m) and is gradually progressed with increased distances and volume of throws. Throughout the long-toss program, the athlete is encouraged to use the trunk and lower extremities while throwing by incorporating a crow-hop and, in addition, lobbing the ball with a slight arc for each of the prescribed distances. Fleisig et al[98] objectively documented the throwing velocity in healthy subjects when asked to throw and state their perceived effort during each throw. They reported when pitchers were asked to throw at 50% effort, radar gun analysis showed that it was approximately 83% of their maximum speed, and at a 75% effort, the pitchers threw at 90% of their maximum effort. This indicates these athletes threw at greater intensities than were suggested, which demonstrates the difficulty in self-imposing velocity limitations. Therefore, we recommend the implementation of a slight arc (versus throwing on a line) in the long-toss program as a means to measure the intensity of a throw and ensure the athlete is not throwing harder than needed at each prescribed distance. The long-toss program is to gradually introduce loads and strains to the shoulder and should be successfully completed before allowing throwing from the mound. In addition, during this phase, position players are allowed to begin a progressive hitting program that begins with swinging a light bat and continues to hitting off a tee, to soft-toss hitting, and to batting practice.

Phase 4: return-to-throwing phase

Phase four of the rehabilitation program involves the continued progression of the ITP. Pitchers are progressed with the ITP to 120 feet (40 m) and, on successful completion, will begin to throw from 60 feet (20 m), using a windup on level ground. Position players are allowed to continue to progress the throwing program to 180 feet (60 m). Phase 2 (throwing from the mound) of the ITP can begin for pitchers after completion of ITP phase 1.[99] Position players at this point can begin performing fielding drills specific to their position. The clinician should continuously monitor the athlete's throwing mechanics and intensities throughout the throwing program.

In addition to the ITP, the athlete is instructed to continue all the previously described exercises to improve upper extremity strength, power, and endurance. The athlete should also continue a stretching program, as well as core, upper extremity, and lower extremity strength training.[100–102] The athlete should also be instructed on a year-round conditioning program on the basis of the principles of periodization, including when to begin such things as strength training and throwing.[103,104] This will aid in preventing both overtraining and beginning throwing when the athlete is poorly conditioned, as well as prepare the athlete for the following season. Wooden et al[105] demonstrated that performing a dynamic variable resistance exercise program significantly increases throwing velocity. Moreover, Escamilla et al also demonstrated that a variety of different resistance exercise programs, including a plyometric training group and a Throwers Ten (TT) training group, increase throwing velocity in high school baseball players of all playing positions.[106,107]

Summary

Optimal treatment of subacromion impingement has been the focus of the review. An effective nonoperative treatment for impingement syndrome is aimed at addressing the underlying causative factor or factors that are identified after a complete and thorough evaluation. Altered biomechanics and/or structural abnormalities in the shoulder complex are often implicated in subacromion impingement. The effective rehabilitation program will focus on regaining full glenohumeral range of motion, reestablish dynamic rotator cuff stability, and implement a progression of resistive exercises to fully restore strength and local muscular endurance in the rotator cuff and scapular stabilizers, combined with sport specific drills and functional activities to allow a return to sport and activity.

Disclosure

The authors report no conflicts of interest in this work.

References

1. Neer CS 2nd. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *J Bone Joint Surg Am*. 1972;54(1):41–50.
2. Matsen FA III, Arntz CT. Subacromial impingement. In: Rockwood CA Jr, Matsen FA III, editors. *The Shoulder*, *Vol*. *II*. Philadelphia (PA): Saunders; 1990:623–646.
3. Andrews JR, Carson WG Jr, McLeod WD. Glenoid labrum tears related to the long head of the biceps. *Am J Sports Med*. 1985;13(5):337–341.
4. Walch G, Boileau P, Noel E, Donell ST. Impingement of the deep surface of the supraspinatus tendon on the posterosuperior glenoid rim: An arthroscopic study. *J Shoulder Elbow Surg*. 1992;1(5):238–245.
5. Neer CS 2nd. Impingement lesions. *Clin Orthop Relat Res*. 1983;(173): 70–77.
6. Flatow EL, Soslowsky LJ, Ticker JB, et al. Excursion of the rotator cuff under the acromion. Patterns of subacromial contact. A*m J Sports Med*. 1994;22(6):779–788.
7. Meister K, Andrews JR. Classification and treatment of rotator cuff injuries in the overhand athlete. *J Orthop Sports Phys Ther*. 1993;18(2): 413–421.
8. Hawkins RJ, Kennedy JC. Impingement syndrome in athletes. *Am J Sports Med*. 1980;8(3):151–158.
9. Johnston TB. The movements of the shoulder joint. A plea for the use of the "plane of the scapula" as a reference for movements occurring at the humero-scapular joint. *Br J Surg*. 1937;25:252–260.
10. Harryman DT 2nd, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA 3rd. Translation of the humeral head on the glenoid with passive glenohumeral motion. *J Bone Joint Surg Am*. 1990;72(9): 1334–1343.
11. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy*. 2003;19(6):641–661.
12. Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. *J Am Acad Orthop Surg*. 2003;11(2):142–151.
13. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med*. 1998;26(2):325–327.
14. Kibler WB. Role of the scapula in overhead throwing motion. *Contemp Orthop*. 1991;22:525–532.
15. Paine RM. The role of the scapula in the shoulder. In: Andrews JR, Wilk KE, editors. *The Athlete's Shoulder*. New York: Churchill Livingstone; 1994:495–512.
16. Codman EA. *The Shoulder: Rupture of the Supraspinatus Tendon and Other Lesions in or about the Subacromial Bursa*. Boston: Thomas Todd; 1934.
17. Iannotti JP, Swiontkowski M, Esterhafi J, Boulaas HJ. Intraoperative assessment of rotator cuff vascularity using laser Doppler flowmetry. Presented at: American Academy of Orthopaedic Surgeons Annual Meeting; 1989; Las Vegas, NV.
18. Moseley HF, Goldie I. The arterial pattern of rotator cuff of the shoulder. *J Bone Joint Surg Br*. 1963;45:780–789.
19. Rathbun JB, Macnab I. The microvascular pattern of the rotator cuff. *J Bone Joint Surg Br*. 1970;52(3):540–553.
20. Sigholm G, Styf J, Körner L, Herberts P. Pressure recording in the subacromial bursa. *J Orthop Res*. 1988;6(1):123–128.
21. Brewer BJ. Aging of the rotator cuff. *Am J Sports Med*. 1979;7(2): 102–110.
22. Bigliani LU, Morrison DS, April EW. The morphology of the acromion and its relationship to rotator cuff tears. *Orthop Trans*. 1986;10:228.
23. Morrison DS, Bigliani LU. The clinical significance of variation in acromial morphology. Presented at: Third Open Meeting of the American Shoulder and Elbow Surgeons; 1987; San Francisco, CA. *Orthop Trans*. 1987;11:234.
24. Kennedy JC, Willis RB. The effects of local steroid injections on tendons: a biomechanical and microscopic correlative study. *Am J Sports Med*. 1976;4(1):11–21.
25. Valtonen EJ. Double acting betamethasone (Celestone Chronodose) in the treatment of supraspinatus tendinitis: a comparison of subacromial and gluteal single injections with placebo. *J Int Med Res*. 1978(6):463–467.
26. Withrington RH, Girgis FL, Seifert MH. A placebo-controlled trial of steroid injections in the treatment of supraspinatus tendonitis. *Scand J Rheumatol*. 1985;14(1):76–78.
27. Foster TE, Puskas BL, Mandelbaum BR, Gerhardt MB, Rodeo SA. Platelet-rich plasma: from basic science to clinical applications. *Am J Sports Med*. 2009;37(11):2259–2272.
28. Bang MD, Deyle GD. Comparison of supervised exercise with and without manual physical therapy for patients with shoulder impingement syndrome. *J Orthop Sports Phys Ther*. 2000;30(3):126–137.
29. Conroy DE, Hayes KW. The effect of joint mobilization as a component of comprehensive treatment for primary shoulder impingement syndrome. *J Orthop Sports Phys Ther*. 1998;28(1):3–14.
30. Dickens VA, Williams JL, Bhamra MS. Role of physiotherapy in the treatment of subacromial impingement syndrome: a prospective study. *Physiotherapy*. 2005;91(3):159–164.
31. Ferro RT, Jain R, McKeag DB, Escobar RA. A nonoperative approach to shoulder impingement syndrome. *Adv Stud Med*. 2003;3:518–526.
32. Michener LA, Walsworth MK, Burnet EN. Effectiveness of rehabilitation for patients with subacromial impingement syndrome: a systematic review. *J Hand Ther*. 2004;17(2):152–164.
33. Moynes DR. Prevention of injury to the shoulder through exercises and therapy. *Clin Sports Med*. 1983;2(2):413–422.
34. Nitz AJ. Physical therapy management of the shoulder. *Phys Ther*. 1986;66(12):1912–1919.
35. Clarke RS, Hellon RF, Lind AR. Vascular reactions of the human forearm to cold. *Clin Sci (Lond)*. 1958;17(1):165–179.
36. Janssen CW Jr, Waaler E. Body temperature, antibody formation and inflammatory response. *Acta Pathol Microbiol Scand*. 1967;69(4): 555–566.

37. Knight KL. *Cryotherapy: Theory, Technique and Physiology*. Chattanooga (TN): Chattanooga Corp; 1985.
38. Lee JM, Warren MP, Mason SM. Effects of ice on nerve conduction velocity. *Physiotherapy*. 1978;64(1):2–6.
39. Stangle L. The value of cryotherapy and thermotherapy in the relief of pain. *Physiotherapy (Canada)*. 1975;27:135–139.
40. Matiland GD. *Vertebral Manipulation*. 4th ed. Boston: Butterworth, 1977.
41. Wyke BD. *The neurology of joints*. Annals of the Royal College of Surgeons. 1967;41(1):25–50.
42. Noyes FR, Mangine RE, Barber S. Early knee motion after open and arthroscopic anterior cruciate ligament reconstruction. *Am J Sports Med*. 1987;15(2):149–160.
43. Stackhouse SK, Eisennagel A, Eisennagel J, Lenker H, Sweitzer BA, McClure PW. Experimental pain inhibits infraspinatus activation during isometric external rotation. *J Shoulder Elbow Surg*. 2013;22(4):478–484.
44. Wilk KE, Andrews JR. Rehabilitation following arthroscopic subacromial decompression. *Orthopedics*. 1993;16(3):349–358.
45. Borstad JD, Ludewig PM. Comparison of three stretches for the pectoralis minor muscle. *J Shoulder Elbow Surg*. 2006;15(3):324–330.
46. Muraki T, Aoki M, Izumi T, Fujii M, Hidaka E, Miyamoto S. Lengthening of the pectoralis minor muscle during passive shoulder motions and stretching techniques: a cadaveric biomechanical study. *Phys Ther*. 2009;89(4):333–341.
47. Reinold MM, Wilk KE, Macrina LC, et al. Changes in shoulder and elbow passive range of motion after pitching in professional baseball players. *Am J Sports Med*. 2008;36(3):523–527.
48. Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. *J Orthop Sports Phys Ther*. 1999;29(10):574–583.
49. Solem-Bertoft E, Thuomas KA, Westerberg CE. The influence of scapular retraction and protraction on the width of the subacromial space. An MRI study. *Clin Orthop Relat Res*. 1993;(296):99–103.
50. Rohrer MJ, Cardullo PA, Pappas AM, Phillips DA, Wheeler HB. Axillary artery compression and thrombosis in throwing athletes. *J Vasc Surg*. 1990;11(6):761–768.
51. Sotta RP. Vascular problems in the proximal upper extremity. *Clin Sports Med*. 1990;9(2):379–388.
52. Kibler WB, Sciascia A, Dome D. Evaluation of apparent and absolute supraspinatus strength in patients with shoulder injury using the scapular retraction test. *Am J Sports Med*. 2006;34(10):1643–1647.
53. Seitz AL, McClure PW, Finucane S, et al. The scapular assistance test results in changes in scapular position and subacromial space but not rotator cuff strength in subacromial impingement. *J Orthop Sports Phys Ther*. 2012;42(5):400–412.
54. Wilk KE, Arrigo CA, Andrews JR. Current concepts: the stabilizing structures of the glenohumeral joint. *J Orthop Sports Phys Ther*. 1997;25(6):364–379.
55. Wilk KE, Arrigo CA. An integrated approach to upper extremity exercises. *Orthop Phys Ther Clin North Am*. 1992;1:337–360.
56. Poppen NK, Walker PS. Forces at the glenohumeral joint in abduction. *Clin Orthop Relat Res*. 1978;(135):165–170.
57. Walker PS, Poppen NK. Biomechanics of the shoulder joint during abduction in the plane of the scapula [proceedings]. *Bull Hosp Joint Dis*. 1977;38(2):107–111.
58. Lephart SM, Pincivero DM, Giraldo JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. *Am J Sports Med*. 1997;25(1):130–137.
59. Lephart SM, Warner JJ, Borsa PA, Fu FH. Proprioception of the shoulder joint in healthy, unstable, and surgically repaired shoulders. *J Shoulder Elbow Surg*. 1994;3(6):371–380.
60. Uhl TL, Gieck JH, Perrin DH, et al. The correlation between shoulder joint position sense and neuromuscular control of the shoulder. *J Athl Train*. 1999;Suppl 34:S10.
61. Padua DA, Guskiewicz KM, Myers JB. Effects of closed kinetic chain, open kinetic chain, and proprioceptive neuromuscular facilitation training on the shoulder. *J Athl Train*. 1999;Suppl 34:S83.
62. Knott M, Voss DE. *Proprioceptive Neuromuscular Facilitation: Patterns and Techniques*. 2nd ed. New York: Hoeber; 1968.
63. Sullivan PE, Markos PD, Minor MAD. *An Integrated Approach to Therapeutic Exercise: Theory and Clinical Application*. Reston (VA): Reston Publishing Company; 1982.
64. Henry TJ, Lephart SM, Stone D, et al. An electromyographic analysis of dynamic stabilizing exercises for the shoulder. *J Athl Train*. 1998;33(Suppl):S74.
65. Wilk KE, Andrews JR, Arrigo C. *Preventive and Rehabilitative Exercises for the Shoulder and Elbow*. 6th ed. Birmingham (AL): American Sports Medicine Institute; 2001.
66. Wilk KE, Arrigo C, Andrews JR. Closed and open kinetic chain exercises for the upper extremity. *J Sports Rehab*. 1996;5:88–102.
67. Blackburn TA, McLeod WD, White B, et al. EMG analysis of posterior rotator cuff exercises. *Athl Train J Natl Athl Train Assoc*. 1990;25:40–45.
68. Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. *Am J Sports Med*. 1999;27(6):784–791.
69. Fleisig GS, Jameson GG, Cody KE, et al. Muscle activity during shoulder rehabilitation exercises. In: Proceedings of NACOB '98, The Third North American Congress on Biomechanics. August 14, 1998; Waterloo, Canada. 223–234.
70. Hintermeister RA, Lange GW, Schultheis JM, et al. Electromyographic activity and applied load during shoulder rehabilitation exercises using elastic resistance. *Am J Sports Med*. 1998;(26):210–220.
71. Jobe FW, Tibone JE, Jobe CM, et al. The shoulder in sports. In: Rockwood CA Jr, Matsen FA III, editors. *The Shoulder*. Philadelphia: WB Saunders; 1990;961–990.
72. Jobe FW, Moynes DR, Tibone JE, Perry J. An EMG analysis of the shoulder in pitching. A second report. A*m J Sports Med*. 1984;12(3):218–220.
73. Pappas AM, Zawacki RM, McCarthy CF. Rehabilitation of the pitching shoulder. *Am J Sports Med*. 1985;13(4):223–235.
74. Townsend H, Jobe FW, Pink M, Perry J. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. *Am J Sports Med*. 1991;19(3):264–272.
75. Moseley JB Jr, Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. *Am J Sports Med*. 1992;20(2):128–134.
76. Jobe FW, Moynes DR. Delineation of diagnostic criteria and a rehabilitation program for rotator cuff injuries. *Am J Sports Med*. 1982;10(6):336–339.
77. Malanga GA, Jenp YN, Growney ES, An KN. EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. *Med Sci Sports Exerc*. 1996;28(6):661–664.
78. Wilk KE, Andrews JR, Arrigo CA, Keirns MA, Erber DJ. The strength characteristics of internal and external rotator muscles in professional baseball pitchers. *Am J Sports Med*. 1993;21(1):61–66.
79. Davies GJ, Dickoff-Hoffman S. Neuromuscular testing and rehabilitation of the shoulder complex. *J Orthop Sports Phys Ther*. 1993;18(2):449–458.
80. Cools AM, Witvrouw EE, Declercq GA, Danneels LA, Cambier DC. Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms. *Am J Sports Med*. 2003;31(4):542–549.
81. Tucker WS, Armstrong CW, Gribble PA, Timmons MK, Yeasting RA. Scapular muscle activity in overhead athletes with symptoms of secondary shoulder impingement during closed chain exercises. *Arch Phys Med Rehabil*. 2010;91(4):550–556.
82. Swanik KA, Lephart SM, Swanik CB, Lephart SP, Stone DA, Fu FH. The effects of shoulder plyometric training on proprioception and selected muscle performance characteristics. *J Shoulder Elbow Surg*. 2002;11(6):579–586.

83. Fortun CM, Davies GJ, Kernozck TW. The effects of plyometric training on the shoulder internal rotators. *Phys Ther*. 1998;78(51):S87.
84. Bosco C, Komi PV. Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. *Acta Physiol Scand*. 1979;106(4):467–472.
85. Cavagna GA, Dusman B, Margaria R. Positive work done by a previously stretched muscle. *J Appl Physiol*. 1968;24(1):21–32.
86. Chu D, Panariello RA. Sport specific plyometrics: baseball pitchers. *Natl Strength Conditioning Assoc J*. 1989;11(3):81–84.
87. Wilk KE. Restoration of functional motor patterns and functional testing in the throwing athlete. In: Lephart SM, Fu FH, editors. *Proprioception and Neuromuscular Control in Joint Stability*. Champaign (IL): Human Kinetics; 2000;415–438.
88. Wilk KE, Voight ML, Keirns MA, Gambetta V, Andrews JR, Dillman CJ. Stretch-shortening drills for the upper extremities: theory and clinical application. *J Orthop Sports Phys Ther*. 1993;17(5):225–239.
89. Brose DE, Hanson DL. Effects of overload training on velocity and accuracy of throwing. *Res Q*. 1967;38(4):528–533.
90. DeRenne C, Ho K, Blitzblau A. Effects of weighted implement training on throwing velocity. *J Appl Sport Sci Res*. 1990;4:16–19.
91. Egstrom GH, Logan GA, Wallis EL. Acquisition of throwing skill involving projectiles of varying weights. *Res Q*. 1960;(31):420–425.
92. Litwhiler D, Hamm L. Overload: effect on throwing velocity and accuracy. *Athletic J*. 1973;53:64–65.
93. Vasiliev LA. Use of different weights to develop specialized speed strength. *Soviet Sports Rev*. 1983;18:49–52.
94. Murray TA, Cook TD, Werner SL, Schlegel TF, Hawkins RJ. The effects of extended play on professional baseball pitchers. *Am J Sports Med*. 2001;29(2):137–142.
95. Voight ML, Hardin JA, Blackburn TA, Tippett S, Canner GC. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *J Orthop Sports Phys Ther*. 1996;23(6):348–352.
96. Chen SK, Simonian PT, Wickiewicz TL, Otis JC, Warren RF. Radiographic evaluation of glenohumeral kinematics: a muscle fatigue model. *J Shoulder Elbow Surg*. 1999;8(1):49–52.
97. Lyman SL, Fleisig GS, Osinski ED, et al. Incidence and determinants of arm injury in youth baseball pitchers: a pilot study. *Med Sci Sports Exerc*. 1998;30(S5):S4.
98. Fleisig GS, Zheng N, Barrentine SW, et al. Kinematic and kinetic comparison of full effort and partial effort baseball pitching. Presented at: American Society of Biomechanics: Proceedings of the 20th Annual Meeting; October 17–19, 1996; Atlanta, GA. 151–152.
99. Reinold MM, Wilk KE, Reed J, Crenshaw K, Andrews JR. Interval sport programs: guidelines for baseball, tennis, and golf. *J Orthop Sports Phys Ther*. 2002;32(6):293–298.
100. Escamilla RF, Lewis C, Bell D, et al. Core muscle activation during Swiss ball and traditional abdominal exercises. *J Orthop Sports Phys Ther*. 2010;40(5):265–276.
101. Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. *Sports Med*. 2009;39(8):663–685.
102. Escamilla RF, Andrews JR. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Med*. 2009;39(7):569–590.
103. Verkhoshansky YV. *Programming and Organization of Training*. Livonia (MI): Sportivny Press, 1988.
104. Wilk KE, Yenchak AJ, Arrigo CA, Andrews JR. The Advanced Throwers Ten Exercise Program: a new exercise series for enhanced dynamic shoulder control in the overhead throwing athlete. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22293772" \o "The Physician and sportsmedicine." Phys Sportsmed. 2011;39(4):90–97. Accessed on January 9, 2014.
105. Wooden MJ, Greenfield B, Johanson M, Litzelman L, Mundrane M, Donatelli RA. Effects of strength training on throwing velocity and shoulder muscle performance in teenage baseball players. *J Orthop Sports Phys Ther*. 1992;15(5):223–228.
106. Escamilla RF, Ionno M, deMahy MS, et al. Comparison of three baseball-specific 6-week training programs on throwing velocity in high school baseball players. *J Strength Cond Res*. 2012;26(7):1767–1781.
107. Escamilla RF, Fleisig GS, Yamashiro K, et al. Effects of a 4-week youth baseball conditioning program on throwing velocity. *J Strength Cond Res*. 2010;24(12):3247–3254.