The Role of Extrinsic and Intrinsic Factors in the Etiology of Rotator Cuff Tendinopathy and the Effect of a Conservative Treatment Strategy

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THE ROLE OF EXTRINSIC AND INTRINSIC FACTORS IN THE ETIOLOGY OF ROTATOR CUFF TENDINOPATHY AND THE EFFECT OF A CONSERVATIVE TREATMENT STRATEGY

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Believe those who are seeking the truth. Doubt those who find it. ~Andre Gide

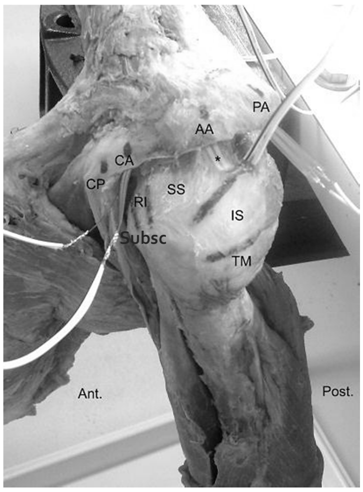
General Introduction

Musculoskeletal disorders of the shoulder are extremely common, with reports of prevalence ranging from 6.9 to 26%.[91] From 6.7 up to even 66.7% of the population has been reported to experience shoulder pain at least once in their lifetime [67] Hence, shoulder disorders are a relevant health problem for clinicians.

Repetitive use of the arm, working above shoulder height and working with the upper limb in an awkward fashion have been shown to be related to shoulder pain.[67] Specific professions such as nurses, construction workers, office workers and musicians seem to be at higher risk for shoulder disease.[67;90] Another population which is prone to shoulder injuries consists of people participating in overhead sports activity.[79] Repetitive overhead throwing challenges the shoulder through high speed and high impact forces in extreme positions.

The most common source of shoulder pain appears to be the rotator cuff [93] with the most prevalent medical diagnosis being subacromial impingement.[1] The term "subacromial impingement" is used to describe irritation from the anteroinferior aspect of the acromion onto the superior aspect of the rotator cuff.[86] The subacromial space of the shoulder is formed superiorly by the coracoacromial arch and limited by the humeral head below. Embracing this humeral head and covered by the coracoacromial arch, the rotator cuff muscles play a considerable role in stabilizing and assisting motion of the most mobile joint in the body. When the arm is elevated, the humeral head and the acromion approach each other, narrowing the subacromial space and impinging the rotator cuff.[40] Thus, subacromial impingement is rather a possible cause of rotator cuff disorders, ranging from tendinopathy to full ruptures, than being the pathology itself. In literature however, the term subacromial impingement is still often used as a medical diagnosis.

The focus of this dissertation is on tendinopathy of the rotator cuff associated with subacromial impingement. The aponeurotic tendon of the rotator cuff is formed by the confluence of four muscles: the supraspinatus, infraspinatus, teres minor and subscapularis as illustrated in figure 1. The insertion of the rotator cuff tendons onto the humeral head is also called the footprint because of the large surface it takes to attach itself to the humerus.[31] Despite the representation in anatomy text books, no strict separation can be made between the different tendons. All are connected to each other and to the joint capsule and ligaments which results in an interwoven "sleeve or cuff" for the humeral head, to which the rotator cuff owes its name.[23]



Coracoacromial arch:
AA - anterior acromion
PA - posterior acromion
CA - coracoacromial ligament
CP - coracoid process

Rotator cuff tendons:
TM - Teres minor
IS – Infraspinatus
SS – Supraspinatus
Subsc – Subscapularis
RI – Rotator Interval

Figure 1. Supero-lateral view of left cadaveric upper limb with borders of rotator cuff tendons traced onto the glenohumeral joint capsule (Figure adapted from Hughes et al. 2012[52], with permission)

1. WHAT'S CAUSING TENDINOPATHY OF THE ROTATOR CUFF?

All factors enhancing subacromial impingement are called *"extrinsic factors"* in the etiology of rotator cuff tendinopathy. These factors are lying outside the tendons and can be divided into anatomical factors, causing primary subacromial impingement, and biomechanical factors, causing secondary subacromial impingement. The extrinsic subacromial compression mechanism in rotator cuff tendinopathy is discussed in part 1.1. Secondary subacromial impingement is associated with changes in scapulothoracic (part 1.1.1.) and glenohumeral kinematics (part 1.1.2.) which can reduce the subacromial space. These altered kinematics have in turn been related to aberrant muscle performance of scapular muscles and the rotator cuff, respectively, and with tightness of the posterior shoulder structures. Good neuromuscular control and adequate scapular and glenohumeral kinematics depend upon accurate proprioceptive information. A deficit of this propriceptive system could contribute to subacromial impingement. Changes in proprioception found in patients with subacromial imipingement are discussed in part 1.1.3.
Rotator cuff disorders associated with subacromial impingement are very common in a specific population, namely overhead athletes.[121] Surprisingly, healthy athletes display similar changes as the ones reported in patients with subacromial impingement (posterior shoulder tightness, rotator cuff muscle imbalance and altered scapular kinematics), which are discussed in part 1.1.4.

Besides subacromial impingement, factors lying inside the tendons were recently found to contribute to tendon degeneration and development of rotator cuff tendinopathy. These are called *"intrinsic factors"* and are described in part 1.2. Intratendinous degeneration is theorized to result from overload, compression and/or stress shielding. Figure 2 gives a non-limited schematic overview of the etiologic factors related to rotator cuff tendinopathy that are discussed below.

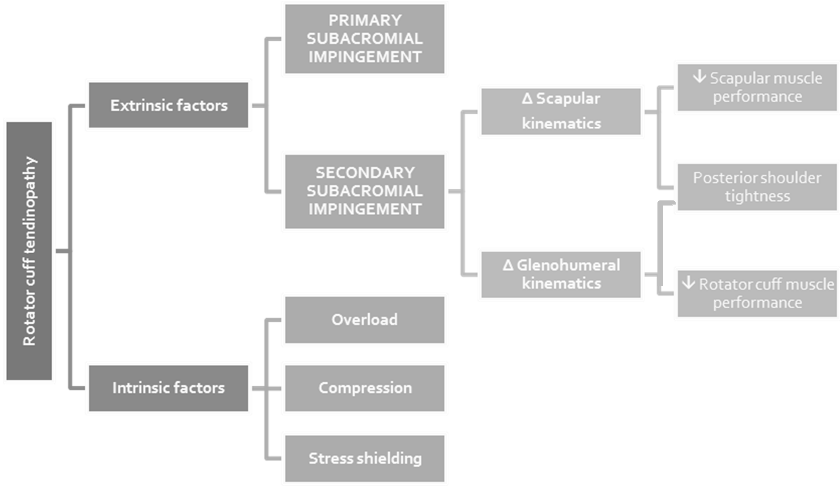


Figure 2. Non-limited schematic overview of etiologic factors related to rotator cuff tendinopathy

1.1 Extrinsic factors related to subacromial impingement

Neer was the first to describe irritation from the anteroinferior aspect of the acromion onto the superior aspect of the rotator cuff as a cause of rotator cuff pathology in 1972.[85] It was believed that the more curved the acromion is, the more the rotator cuff becomes impinged.[9] This is called **primary subacromial impingement** because of the structural nature of the problem. Next to a curved acromion, prominent osseous changes to the inferior aspect of the acromioclavicular joint or coraco-acromial ligament may result in structural narrowing of the subacromial space.[101]

However, several authors have questioned the primary subacromial impingement theory. If primary subacromial impingement could explain all rotator cuff pathology, this would imply a very strong correlation between acromial abnormalities and rotator cuff pathology. Nonetheless, it was shown that a lot of patients with rotator cuff pathology don't present with acromial abnormalities[42] while a lot of persons who do show abnormalities do not necessarily develop rotator cuff pathology.[122] Furthermore, the acromioplasty procedure (in which the anterior part of the acromion is removed to enlarge the subacromial space) failed to show superior results compared with conservative treatment.[15;16;46;47] This suggests that other than anatomic factors must be contributing to rotator cuff tendinopathy.

Besides structural narrowing of the subacromial space, functional narrowing can occur in an anatomically normal sized subacromial space. This is termed **secondary subacromial impingement**. Scapular and humeral kinematics can dynamically influence the size of the subacromial space. Factors that alter these kinematics are therefore capable of reducing subacromial space size.

1.1.1 Changes in scapular kinematics

Ludewig et al. examined three-dimensional scapular position and motion in healthy subjects using electromagnetic motion tracking with transcortical pins into the scapula.[65] They reported that at rest the scapula is 5.4± 1° upwardly rotated, 41.1±2° internally rotated and 13.5±2° anteriorly tilted in healthy subjects. During elevation, most studies included in a review of Struyf et al. agreed that the scapula moves to scapular upward rotation, external rotation and posterior tilt. Ludewig et al. found a scapular upward rotation of 39°, scapular external rotation of 2° and scapular posterior tilt of 21° during elevation in healthy subjects..[65] Reports on scapulothoracic kinematic alterations, also called scapular dyskinesis, in *patients with subacromial impingement* show mixed results. A review of Struyf and co-workers concluded that the majority of studies report a decreased upward rotation[39;62], posterior tilt[39;62;68] and external rotation[62] of the scapula during elevation of the arm in patients with subacromial impingement.[107] Of the other studies included in the review examining upward rotation, 1 showed increased upward rotation[75] and 3 showed no difference[44;50;68]. One of the other studies investigating posterior tilt found an increase[75] and the remaining 2 found no difference[44;50]. Concerning scapular external rotation, there is 1 other study that found an increase[50] and 4 that found no difference. Varying methodology can explain these diverging results.

Scapular dyskinesis observed in patients with subacromial impingement, with decreased upward and external rotation and posterior tilt, is believed to compromise the subacromial space by bringing the acromion in closer proximity with the humeral head. Solem-Bertoft et al. showed a relation between protraction of the scapula and reduction of the subacromial space.[105] Atalar further provided evidence by reporting that when scapular motion is limited, the subacromial space becomes more narrow.[4] Vice versa, Seitz et al. showed increased subacromial space when the scapula was manually assisted to upward rotation and posterior tilt during a "scapular assistance test".[102]

Several factors have been postulated to give rise to scapular dyskinesis amongst which are posterior shoulder tightness, aberrant scapular muscle performance, posture and pectoralis minor tightness.[101] In view of the studies of this dissertation posterior shoulder tightness and aberrant scapular muscle performance are discussed more into detail below. No causational relationship between scapular dyskinesis and the development of subacromial impingement has been determined yet. Evidence is limited to observation of scapular kinematic alterations in the presence of posterior shoulder tightness and aberrant scapular muscle performance, and demonstration of posterior shoulder tightness and aberrant scapular muscle performance in patients with subacromial impingement.

Posterior shoulder tightness

Posterior shoulder tightness is believed to be the result of both capsular tightness and muscular contracture. This manifests clinically as decreased glenohumeral cross-body adduction and internal rotation mobility.[115] Compared with the healthy shoulder, the affected shoulder of patients with subacromial impingement was identified to have posterior shoulder tightness.[82;114;118] Whether posterior shoulder tightness or subacromial impingement pathology comes first, is not known at the present time. Posterior shoulder tightness might result from avoidance of painful internal rotation in patients with subacromial impingement. Conversely, posterior shoulder tightness might be present in healthy subjects and result in subacromial impingement because of altered shoulder kinematics.

Several authors have examined healthy subjects with posterior shoulder tightness and have shown that the scapula is in a more anteriorly tilted, protracted and less upwardly rotated position.[10;59;112] It is believed that a loss of glenohumeral internal rotation may force the scapula in this position, ultimately resulting in a loss of scapular control.[18;56] This altered scapular position would place the acromion closer to the rotator cuff tendons and increase the potential for impingement. However, Thomas et al. [110] found a positive correlation between posterior capsule thickness and scapular upward rotation during glenohumeral abduction. They theorized that this can be explained by the increased pull onto the scapula by the stiffened posterior capsule. Though it is clear that posterior shoulder tightness alters scapular kinematics, so far there is no consensus as to the direction of these alterations. Moreover the role of posterior shoulder tightness in subacromial impingement remains unclear.

Aberrant scapular muscle performance

The trapezius and serratus anterior muscles function to stabilize the scapula and induce upward, external rotation and posterior tilt.[5;53] Changes in muscle activity or muscle force of the trapezius and serratus anterior in patients with rotator cuff tendinopathy could therefore alter scapular kinematics and contribute to subacromial impingement.

Concurrent with scapular kinematic alterations, aberrant **scapular muscle activity** was found in patients with subacromial impingement. Activity of the serratus anterior, middle and lower trapezius was found to be decreased while upper trapezius muscle activity was found to be increased.[25;29;34;62]

However, caution is needed when formulating conclusions since a review of Chester et al. on the impact of subacromial impingement syndrome on scapular muscle activity patterns showed that these findings are not consistent.[21] The highest quality studies found by the authors only provide strong evidence for increased upper trapezius activation and delayed activation of the lower trapezius in patients with subacromial impingement syndrome.

Next to altered muscle activity, decreased **scapular muscle force** was shown in patients with subacromial impingement. Cools et al. revealed lower protraction force on the injured side of overhead athletes compared with the non-injured side and compared with a healthy athletic population.[30] This provides further evidence for deficient serratus anterior functioning which is an important upward rotator of the scapula.

To link altered scapular muscle performance with scapular dyskinesis, studies on the effect of **shoulder muscle fatigue** on scapular kinematics may be illustrative. Borstad et al. aimed to specifically fatigue the scapular muscles in the shoulders of asymptomatic subjects with a push up plus exercise.[13] Following the task, the upper trapezius showed higher activity during arm elevation and the scapula showed decreased posterior tilt and external rotation. No influence on upward rotation of the scapula was seen. This decreased scapular motion could result in narrowing of the subacromial space and is in line with findings in patients with rotator cuff tendinopathy.

General shoulder muscle fatigue, which occurs in overhead athletes or workers with regular exposure to overhead work, is proposed to result in neuromuscular alterations that contribute to shoulder pathology. McQuade et al. used a resisted elevation task to fatigue the shoulder similar to overhead work and observed a decreased scapulohumeral rhythm (i.e. the movement of the scapula across the thoracic cage in relation to the humerus), which implies more scapular upward rotation, as muscle fatigue increased.[78]

In agreement, Ebaugh et al. also reported increased upward and external rotation of the scapula after an elevation fatigue protocol that resembled an industrial assembly task.[36] Moreover, they showed that repetitive overhead activities fatigue the scapular muscles to a lower degree than the glenohumeral muscles which allows the scapula to compensate in order to obtain full elevation. This results in contrary changes than the ones seen after specifically fatiguing the scapular muscles by a knee push up plus exercise.[13] During repetitive arm elevations in a non-fatigued status, the scapulohumeral rhythm or synchronization between movement of the humerus and the scapula is balanced to allow the most efficient elevation of the arm. After overhead working or overhead throwing fatigue this balance might be disturbed.The direct consequence of these changes on soft tissues in the subacromial space remains unclear.

1.1.2 Changes in glenohumeral kinematics

Determining the position of the bottom of the subacromial space, kinematics of the humerus also play an important role in narrowing of the subacromial space. A superior and anterior translation of the humeral head, bringing it in closer contact with the coracoacromial arch[40;43], was consistently seen in patients with rotator cuff tendinopathy.[63;99] This finding has been associated with posterior shoulder tightness and aberrant rotator cuff muscle performance.

Posterior shoulder tightness

As described above, posterior shoulder tightness and associated decreased internal rotation range of motion has been shown on the injured side of patients with subacromial impingement.[82;118] Harryman et al. investigated the effect of posterior shoulder tightness on glenohumeral kinematics in cadavers.[48] They reported significantly increased anterior and superior translation of the humeral head during shoulder flexion after surgical tightening of the posterior capsule. This suggests that the presence of posterior shoulder tightness in patients with subacromial impingement could be responsible for the altered humeral head kinematics and could contribute to impingement of the subacromial tissues. No studies have confirmed this.

Aberrant rotator cuff muscle performance

Decreased rotator cuff performance might also relate to proximal migration of the humeral head in patients with rotator cuff tendinopathy. McCully et al. performed a suprascapular nerve block to paralyze the supraspinatus and infraspinatus in healthy subjects and found increased activation of the deltoid.[76] Optimal balance between the rotator cuff and deltoid is necessary for good glenohumeral kinematics. The rotator cuff pulls the humeral head downward and neutralizes the superior pull of the deltoid on the humerus.[89] Impairment of rotator cuff/deltoid balance could be responsible for the increased superior translation of the humeral head noted in patients with subacromial impingement symptoms.

Several studies investigated **rotator cuff muscle activity** in patients with subacromial impingement symptoms. (Table 1)

Authors	**Results**	**Compared with…**
Diederichsen et al. [34]	↓ infraspinatus activity during external rotation ↑ supraspinatus activity during dynamic abduction	Healthy subjects
Brox et al.[14]	↓ infraspinatus activity during isometric abduction unaltered supraspinatus activity during isometric abduction	The unaffected side
Myers et al.[81]	↓ rotator cuff coactivation +↑ middle deltoid activity from 0 to 30° elevation ↓ rotator cuff coactivation from 30 to 60° elevation ↑ rotator cuff coactivation from 90 to 120° elevation	Healthy subjects
Reddy et al.[94]	↓ rotator cuff but also ↓ deltoid activity during scapular abduction	Healthy subjects

Table 1. Rotator cuff muscle activity changes in patients with subacromial impingement symptoms.

From these studies, it is clear that rotator cuff muscle activity patterns are altered in subjects with subacromial impingement symptoms but currently no conclusions can be drawn as to rotator cuff/deltoid muscle activity balance due to varying results.

Studies on **rotator cuff muscle force** also showed variations in patients with subacromial impingement. Decreased isometric, concentric and eccentric torque of the rotator cuff have been detected in patients suffering from subacromial impingement.[14;69;113;118] Moreover muscular imbalance of rotator cuff force occurs as a result of external rotation force deficits exceeding internal rotation force deficits.[69] This could be related to imbalanced forces onto the humeral head and altered humeral kinematics.

Examining the effect of **rotator cuff muscle fatigue** provides further evidence on the relation between decreased rotator cuff muscle performance and superior humeral head migration.[20;99] After fatiguing the supraspinatus in a prone horizontal abduction position in healthy subjects, Chen et al. radiographically determined significant superior migration of the humeral head within the initiation of abduction.[20] Teyhen et al. and Royer et al. confirmed this by use of fluoroscopic assessment of humeral head position.[99;108]
Fatigue of the rotator cuff in overhead athletes or overhead workers is theorized to be a risk factor for developing subacromial impingement. Chopp et al. fatigued the rotator cuff with a simulated job task and strengthened this suggestion by showing increased superior translation of the humeral head after continuous overhead work.[22]

1.1.3 Changes in proprioception

From the investigations described above, it can be derived that neuromuscular control is altered in subjects with rotator cuff pathology associated with subacromial impingement. The mechanism through which shoulder injury gives rise to compromised neuromuscular control is not fully understood. Vice versa it is not known if compromised neuromuscular control could be rather the cause and contributing to shoulder injuries. As good neuromuscular control depends on adequate afferent information from the peripheral structures, proprioception likely plays a crucial role in patients with rotator cuff disorders. Proprioception is defined as the afferent information, arising from peripheral areas of the body, that contributes to joint stability, postural control and motor control.[97] Three submodalities of proprioception can be distinguished, including joint position sense, kinesthesia and sensation of force.[97] Joint position sense is the appreciation and interpretation of the position and orientation of a joint in space. Kinesthesia is the ability to appreciate and interpret joint motions and sensation of force is the ability to appreciate and interpret force applied to or generated within a joint.[84]

The number of investigations on proprioception in subjects with subacromial impingement and rotator cuff tendinopathy is limited. Machner et al. showed impaired **kinesthesia** on the affected side compared with the non-affected side in subjects with subacromial impingement.[70] The authors believe that the changes in mechanoreceptors described in the subacromial bursa and the coracoacromial ligament are causing these changes in movement sense. Safran and colleagues also showed a kinesthetic deficit in baseball pitchers with rotator cuff tendinopathy.[100] They suggested that microtrauma of the capsule due to repetitive throwing either results in

damage of peripheral afferent receptors or in stretching the capsuloligamentous complex augmenting threshold to stimulation of the receptors.
Anderson and Wee assessed joint position sense in subjects with chronic rotator cuff pathology using an active position-matching task.[3] They showed significantly impaired **joint position sense**, especially at higher elevation degrees. They suggested the higher level of pain in this arc of motion was responsible for their results. Next to tissue damage, as described by Machner et al[70] and Safran et al[100], pain is believed to be an important factor causing proprioceptive deficits. By overriding proprioceptive information, the nociceptive signals may inhibit proprioceptive information to reach the supraspinal level. These proprioceptive deficits could sustain the disease process and induce ongoing symptoms. However, it is unclear whether proprioceptive deficits are a result of, or contribute to the pathologic process.
No studies have examined **sensation of force** in subjects with rotator cuff pathology.

1.1.4 Special considerations in overhead athletes

Repetitive throwing at high velocities places high demands on the shoulder. These demands differ between different sports disciplines. Firstly, it needs to be mentioned that biomechanics of the throwing motion can vary largely between sports. The baseball pitch serves as a basis for describing all overhead throws. A pitch is broken into six phases: wind-up, stride, arm cocking, arm acceleration, arm deceleration and follow through. However, a golf swing for example looks very different with a large adduction motion of the lead arm during the backswing, followed by the downswing and follow through phase. Another overhead sport with very specific biomechanics is swimming, in which the front crawl stroke for example requires very large bilateral shoulder motion against resistance of the water.
Secondly, the use of a club in golf or a racket in tennis for example to strike the ball, opposed to throwing or releasing a ball, also affects the shoulder as this increases lever arm. Thirdly, another aspect in which sports demands differ is whether the athlete stands alone on the field or is playing in a team. In volleyball and handball for example players are at different positions in a team which might also have an impact on shoulder load. And lastly, contact sports, like for example American football, can place a different kind of stress on the shoulder.

Over time, performing overhead sports activity leads to chronic adaptations in the shoulders of the athletes. Although these changes may be adaptive, some or a combination are presumed to be linked with shoulder pathology and decreased performance. Three important adaptations that are very close to changes described in patients with subacromial impingement are discussed below.

The dominant shoulder of an overhead athlete has been shown to develop **posterior shoulder tightness** in response to long-term overhead activity.[111] Glenohumeral internal rotation range of motion loss was identified in the dominant arm of healthy baseball[11;110], tennis[38], volleyball, basketball and handball players[6] and swimmers[98]. Burkhart et al. termed this asymmetric range of motion glenohumeral internal rotation deficit (GIRD). This is theorized to result from high stresses onto the posterior shoulder capsule and muscles when decelerating the throwing shoulder.[12] Repetitive microtrauma can occur and result in adaptive thickening of the posterior capsule and muscles conform with Wolff's Law (the body adapts to the load it is placed under).[18] Thomas et al. provided evidence for a negative correlation between posterior capsule thickness and glenohumeral internal rotation.[110]
As depicted above, posterior shoulder tightness is related to changes in glenohumeral and scapular kinematics that can augment compression of the rotator cuff tendons in the subacromial space, causing secondary impingement. Wilk et al. showed that athletes with GIRD of >20° are at higher risk for shoulder injuries.[120] It remains unclear however how the subacromial space is affected by posterior shoulder tightness.

Additionally, the eccentric decelerating function of the posterior shoulder muscles opposed to the concentric accelerating function of the anterior shoulder muscles is thought to result in **rotator cuff force imbalance**, as observed in overhead athletes. The external rotators (ER) have been indicated to be proportionally weaker than the internal rotators (IR) in overhead athletes.[6;116] It is plausible that this imbalance influences glenohumeral kinematics. Leong et al. showed that the distance between the acromion and the humeral head is related to external rotation force and consequently to ER/IR force balance.[61]

Lastly, **altered scapular position and motion** has been observed at the dominant side of overhead athletes. Compared with the non-throwing shoulder, the throwing shoulder is in a more protracted, internally rotated and anteriorly tilted position.[59;88] This movement combination is assumed to bring the acromion into closer contact with the subacromial structures. In contrast, other authors found dominant scapular motion during elevation to occur with more upward rotation compared with the non-dominant side in overhead athletes.[28;83] Possibly only a subset of athletes develop scapular dyskinesis. Silva et al. showed that the subacromial space in the shoulders of tennis players that present with scapular dyskinesis reduces to a greater amount during abduction compared with athletes without scapular dyskinesis.[104]

1.2 Intrinsic factors related to tendon degeneration

There is a growing body of evidence to support a role for intrinsic factors in the pathogenesis of rotator cuff tendinopathy. Signs of degeneration have been found not only on the bursal side of the rotator cuff tendons, but also on the articular side and intratendinous. These changes are unlikely caused by friction of the coracoacromial arch. Hashimoto et al. identified diffuse degenerative changes including tendon thinning, fibre disorientation, degeneration, calcification, fatty infiltration and vascular proliferation.[49]
Soslowsky et al. studied the shoulder of rats.[106] These animals have an anatomy of the shoulder comparable to the human shoulder as they have an enclosed arch through which the supraspinatus tendon must pass. They found that mechanical impingement alone was not sufficient to induce rotator cuff tendinopathy. The presence of **overload** was crucial in development of pathology. Caution should be taken when transfering the results to the human shoulder.

Insertional rotator cuff tendinopathy can be considered as an overuse injury, but is predisposed by pre-existing weakening of the tendon. The rotator cuff tendons experience a lot of **compression**. The human body adapts to these compressive forces by transforming the tendon into a more fibrocartilaginous tissue.[2] Fibrocartilage is found at tendon attachment to bone and is uncharacteristically long (20mm) in the supraspinatus tendon compared with other tendons (5-7mm).This tissue, resembling more cartilage than tendon, cannot withstand high tensile loads. This is thought to be the reason why the supraspinatus is more prone to degeneration.
Furthermore, it was shown that not overuse but rather underuse or **stress shielding** (i.e. removal of normal stress) plays an important role in development of degeneration.[2] Not all parts of the rotator cuff tendons are loaded to the same amount. For example, when moving from adduction to full abduction the joint side fibres become relatively elongated while the bursal-side fibres become shortened.[51] This may lead to atrophic changes in response to the lack of tensile load.
Moreover, the special structure of the rotator "cable and crescent" structure (figure 3) enhances stress-shielding. It was shown that some tendon fibers of the supraspinatus and infraspinatus run perpendicularly over others at some distance from the insertion and form a strong and thick cable (C in figure 3).[17] This rotator cable delineates the thinner rotator crescent (B in figure 3), shaped like a horseshoe, which contains a weaker part of the supraspinatus and infraspinatus tendons close to the insertion. The rotator crescent lies laterally from the cable when seen from superior. Tendon fibers lying medially from the cable can transmit tensile forces through this rotator cable to the insertion on the humerus. Due to the function of the cable, the rotator crescent receives

less tensile forces and is relatively underloaded and potentially more prone to atrophy and degeneration.

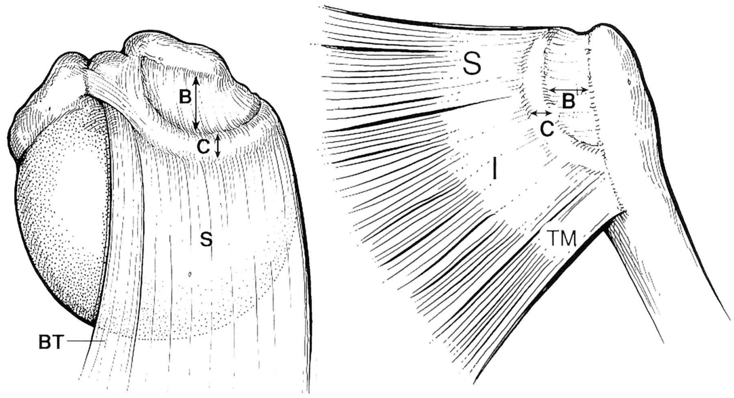


Figure 3. Rotator cable and crescent structure. (B. Mediolateral diameter of crescent; C. Rotator cable; S, Supraspinatus; BT, Biceps tendon; I, Infraspinatus; TM, Teres minor)

2. Current concepts in conservative rehabilitation of patients with rotator cuff tendinopathy

Reviews agree that treatment of patients with rotator cuff tendinopathy/ subacromial impingement should initially be conservative.[45;57] No better outcome was shown after surgery compared with conservative treatment.[15;16;35;46;47] The available literature is supportive of the use of exercise for reducing pain and improving shoulder function.[41;55;57] Performing these exercises at home may be as effective as supervised exercises.[117;119] Manual therapy has shown to augment the effect of exercises.[7;24;103]

Randomized controlled trials have used a wide variety of rehabilitation protocols which prohibits comparison and the use of a conclusive evidence-based gold standard program. Reviews indicate that there remains a need for well-defined clinical trials on specific interventions for the treatment of subacromial impingement.[41] A thorough clinical examination is recommended to precede the choice of treatment goals and appropriate techniques and exercises.[37] The focus of physiotherapeutic treatment is on increasing flexibility from both soft tissue and articular structures and improving scapular and rotator cuff muscle performance.[37] The rationale behind this is to normalize glenohumeral and scapulothoracic kinematics in order to decrease impingement and allow the subacromial structures to heal.

2.1 Posterior shoulder stretching

Given the evidenced impact of posterior shoulder tightness on shoulder kinematics, increasing posterior shoulder flexibility is recommended in rehabilitation of patients with rotator cuff tendinopathy associated with subacromial impingement. Both self-stretching and stretching by a therapist are used in clinical practice. Despite its common use, evidence on these techniques is scarce.

In literature, stretching the posterior shoulder structures is often part of standardized treatment protocols in trials on rehabilitation of patients with subacromial impingement. Patients in the study of McClure et al. performed among other strengthening and stretching exercises two stretches to decrease posterior shoulder tightness: the towel internal rotation and the cross body stretch.[74] They found that a gain in internal rotation ROM was correlated with functional improvement.

Most studies, however, have examined healthy asymptomatic subjects. Manske et al. compared 4 weeks cross-body self-stretching with and without joint mobilization (dorsal glides) by a therapist to decrease posterior shoulder tightness.[72] Internal rotation increased in both groups. Higher increase was shown when self-stretching was combined with joint mobilization but the difference was non-significant.

Cools et al. compared 3 weeks angular (sleeper stretch, cross body stretch) and non-angular (dorsal and caudal glides) stretching, both performed by a physiotherapist in healthy athletes and athletes with subacromial impingement.[27] Internal rotation ROM increased equally in both groups and after both stretching programs. McClure et al. compared two stretching exercises frequently used: the cross-body and the sleeper stretch.[73] Internal rotation ROM increased to a larger but non-significantly different amount after performing the cross-body stretch compared with the sleeper stretch. Finally, it was shown that both the sleeper stretch and a horizontal adduction muscle energy technique (hold-relax) can immediately improve internal rotation ROM.[60;80] The idea behind stretching the posterior shoulder structures in patients with subacromial impingement is to restore shoulder kinematics and to diminish impingement of the rotator cuff. This remains speculative as no evidence is available on the impact of stretching the posterior shoulder on glenohumeral and scapular kinematics nor on the size of the subacromial space.

2.2 Scapular muscle strength training

The association between abnormal scapular kinematics and rotator cuff pathology has been well established in literature.[66] The trapezius and serratus anterior are the most important muscles for restoring scapular motion.[5] Exercise protocols should include exercises with selective activation of the weaker muscles and minimal activation of the hyperactive muscles. Several studies have been performed identifying exercises with a low upper trapezius/lower trapezius (UT/LT), upper trapezius/middle trapezius (UT/MT) and upper trapezius/serratus anterior (UT/SA) ratio. Cools et al. demonstrated low UT/MT and UT/LT ratio during prone extension, prone horizontal abduction with external rotation at 90°, side lying external rotation and side lying shoulder flexion.[26] Ludewig et al. investigated UT/SA ratio during variations of the push up plus exercise.[64] This exercise is performed like a regular push up but with an additional plus phase, consisting of a scapulothoracic protraction and retraction. It is known that this exercise exhibits large serratus anterior activity, especially during the "plus" phase at the end of the push up.[64] Low ratio UT/SA was found during the standard push up plus and the knee push up plus. Up to now, there are no studies available investigating the effect of an isolated scapular muscle strength training program in patients with subacromial impingement related shoulder pain.

2.3 Rotator cuff muscle strength training

Strengthening the rotator cuff muscles is recommended to increase the inferior pull onto the humeral head. Exercises that have been shown to elicit high rotator cuff muscle EMG activity are resisted internal and external rotation with the arm along the body[32], internal rotation at 90° of abduction[33], prone horizontal abduction with external rotation and full can (thumb up) elevation in the scapular plane[96].

An exercise that is often used in treatment of patients with subacromial impingement is the empty can (thumb down) elevation in the scapular plane. Based on literature, however, it is not recommended.[95] The empty can exercise elicits a higher amount of middle and posterior deltoid activity compared with the full can exercise.[96] Moreover, pointing the thumb downward requires humeral internal rotation during abduction and this does not allow the greater tuberosity to clear from under the acromion.[95] Scapular kinematics were also found to be disadvantageous during the empty can exercise with scapular winging (increased internal rotation) and increased anterior tilting.[109] To our knowledge, no studies have investigated the effect of isolated rotator cuff strength training in patients with subacromial impingement.

2.4 Eccentric training

Next to extrinsic factors, impinging the rotator cuff tendons, intrinsic factors, causing degeneration of the tendon, have been shown to contribute to rotator cuff tendinopathy.[101] As a result, physiotherapy should not only focus on decreasing impingement but should additionally address this tendon degeneration. In patella and Achilles tendinopathy, eccentric training has shown to not only decrease pain and improve function but also repair tendon tissue.[58;71;87] The Achilles tendon was shown to respond to eccentric training load with an increased collagen production.[58] As to rotator cuff tendinopathy, three studies have been executed and have shown promising clinical results.[8;19;54]

Jonsson et al. investigated the effect of an eccentric empty can (thumb down) abduction exercise for the supraspinatus without additional treatment in 9 patients with subacromial impingement.[54] The exercise was performed at home for 3 sets of 15 repetitions, twice a day, every day of the week for 12 weeks and load was gradually increased to reach the pain-level. Five patients were satisfied with treatment and showed significantly less pain and better function after 12 weeks of training and at 52-weeks follow-up.

Bernhardsson et al. investigated the effect of eccentric rotator cuff training added with scapular stabilizing exercises and upper trapezius stretching in 10 subjects with subacromial impingement.[8] The exercises were performed at the same volume and frequency as in the study of Jonsson et al. and they were dosed to reach a pain-level between 0 and 5 on a VAS of 10. In 8 of 10 subjects pain had significantly decreased and in all subjects shoulder function had significantly increased after 12 weeks. Due to small sample size and the lack of a control group in both studies, conclusions cannot be drawn.

Recently, Camargo et al. showed good results with an isokinetic eccentric training program in a larger group of patients with subacromial impingement (n=20).[19] The shoulder abductors were trained twice a week for 6 weeks with eccentric training between 20° and 80° of abduction at a speed of 60°/s (3 sets of 10 repetitions). Despite the overall lower volume of the training compared with the study of Jonsson and Bernharsson and colleagues, they showed significantly decreased pain and improved shoulder function. Change in isokinetic parameters however was small with overall small effect sizes.

Eccentric exercises may be able to uniformly stress a healing area of the tendon in a controlled manner, and thereby stimulate healing once an injury has occurred. Possibly these high tensional loads onto the fibrocartilaginous tendon provide a signal for the tendon cells to increase metabolism and again become stronger to resist tension. It is not clear if a change in rehabilitation to eccentric exercises is more efficacious than current techniques.

2.5 Kinetic chain approach for shoulder rehabilitation

During daily activities as well as during sports activities, the human body moves like a kinetic chain.[77] This kinetic model depicts the body as a linked system of interdependent segments, often working in a proximal-to-distal sequence to achieve a desired goal at the distal segment. Clinicians recognize the need to address the trunk and lower limb muscles during shoulder exercises to train the shoulder in a way that it is used during functional activities. During rapidly forward reaching with the right arm, for example, a consistent pattern of activation is produced: the right tensor fascia latae and rectus femoris are activated, the left semitendinosus and gluteus maximus are activated and finally the right erector spinae is activated before the deltoid starts to contract.[123] Normal motor patterns of forward arm elevation demonstrate ipsilateral activation of hip extensors before deltoid activation.[123] Besides functional connections between muscles, anatomical connections have been described between synergistic muscles.[92]

Despite its wide clinical use, no evidence exists on the effect of exercises integrating the shoulder in the kinetic chain during rehabilitation of patients with subacromial impingement related rotator cuff tendinopathy.

3. Outline and aims of the thesis

Based on available literature it can be concluded that both extrinsic factors, causing subacromial impingement of the rotator cuff, and intrinsic factors, causing intratendinous degeneration of the rotator cuff, might play a role in patients with rotator cuff tendinopathy. Successful conservative treatment of patients with rotator cuff tendinopathy is inextricably linked to profound knowledge and understanding of the associated mechanisms.

PART I. MECHANISMS ASSOCIATED WITH ROTATOR CUFF TENDINOPATHY

The *first aim* of this dissertation is to further investigate **the role of proprioception** in patients with rotator cuff tendinopathy.

Dysfunction of neuromuscular control is well documented in patients with subacromial impingement. As proprioception provides the information on position, motion and applied force, proprioceptive deficits might be associated with dysfunctional neuromuscular control. Studies have indicated disturbed kinesthesia and joint position sense in patients with rotator cuff pathology. Force sensation, the third submodality of proprioception next to kinesthesia and joint position sense, however has never been assessed in patients with rotator cuff pathology. Chapter 1 illustrates a study on "The impact of rotator cuff tendinopathy on proprioception, measuring force sensation".

The *second aim* is to elaborate knowledge on the **size and behavior of the subacromial space in overhead athletes**, a population at risk for subacromial impingement and rotator cuff tendinopathy.

a. The influence of training

Previous studies showed that the dominant shoulder of overhead throwing athletes differs from the non-dominant side, possibly due to adaptation to overhead sports activities. These observations are very similar to some changes seen on the injured side of patients with subacromial impingement. However, it is not clear how this affects the size of the subacromial space. We conducted a descriptive study in which the acromiohumeral distance (AHD) was compared between the dominant and non-dominant shoulder of 62 healthy overhead athletes. Both elite handball players and recreational overhead athletes of different sports disciplines were recruited for this study. Results are presented in chapter 2: "Sonographic evaluation of the acromiohumeral distance in elite and recreational female overhead athletes".

b. The influence of muscle fatigue

Besides adaptations at the shoulders of overhead athletes, functional muscle fatigue induced by overhead throwing was postulated to play a role in development of subacromial impingement. The shoulder joint obtains very little stability from passive structures like the capsule and the ligaments. Hence, mainly shoulder muscles are responsible for optimizing kinematics. When fatigued, studies have shown disturbed neuromuscular control with changes in kinematics that could compromise the subacromial space. A study was performed in which the AHD was measured by ultrasound imaging before and after overhead throwing fatigue and in addition, changes in three-dimensional scapular position were recorded. Outcome of this study is described in chapter 3: "Acromiohumeral distance and three-dimensional scapular position change after overhead throwing fatigue".

c. The influence of posterior shoulder tightness

One of the adaptations often seen at the dominant side of overhead athletes is posterior shoulder tightness, which is associated with internal rotation range of motion loss. Previous studies showed that posterior shoulder tightness is related to alterations of glenohumeral and scapulothoracic kinematics. The consequence of these alterations for subacromial space size remains unexplored. Hence, we recruited 62 recreational overhead athletes that displayed an internal rotation deficit compared with the non-dominant side and measured the acromiohumeral distance. Chapter 4 presents the results of this study on "Quantifying acromiohumeral distance in overhead athletes with glenohumeral internal rotation loss and the influence of a stretching program".

PART II. CONSERVATIVE TREATMENT OF PATIENTS WITH ROTATOR CUFF TENDINOPATHY

3. The *third aim* of this thesis was to contribute to evidence on conservative treatment in patients with rotator cuff tendinopathy by further investigating three aspects of this treatment: posterior shoulder stretching, eccentric training and scapular muscle balance training.

a. Posterior shoulder stretching in overhead athletes

Both healthy overhead athletes and subjects with rotator cuff tendinopathy associated with subacromial impingement have been shown to regularly suffer from posterior shoulder tightness and GIRD. Stretching the posterior shoulder to restore internal rotation

ROM is suggested in management of subacromial impingement in overhead athletes. Moreover, stretching has been recommended to prevent shoulder injuries and enhance sports performance. It is not clear if stretching also affects glenohumeral and scapular kinematics and therefore if this would alter the size of the subacromial space. We investigated the change of AHD after a 6 week sleeper stretch program in healthy overhead athletes. This is the second part of the study presented in Chapter 4: "Quantifying acromiohumeral distance in overhead athletes with glenohumeral internal rotation loss and the influence of a stretching program".

b. Scapular muscle balance training in healthy subjects

To increase muscle strength is an important aim of treatment in patients with rotator cuff tendinopathy. In light of enlarging the subacromial space, obtaining correct scapular position and motion is crucial. The serratus anterior has been shown to contribute to impingement sparing kinematics of the scapula. The challenge is to find exercises that selectively activate the serratus anterior with minimal contribution of the upper trapezius to improve UT/SA muscle balance. In this view, the knee push up plus is an optimal exercise. This exercise is performed like a push up exercise but a plus phase, an additional protraction-retraction, is added after the push up. A study was performed in which scapular muscle activity was recorded during 7 variations of the knee push up plus. Four of these variations were chosen to evaluate the influence of the kinetic chain through leg extension. Chapter 5 reports the results of the study "Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity".

c. Eccentric training in patients with rotator cuff tendinopathy

Chapter 6 describes a randomized clinical study on eccentric training in patients with rotator cuff tendinopathy. Since evidence is growing on the contribution of intrinsic degeneration to development of rotator cuff tendinopathy, this should be acknowledged in treatment as well. From research on physiotherapy treatment in other tendinopathies, like for example Achilles tendinopathy, we've learned that eccentric training leads to better outcome and even regeneration of tendon tissue. Given the similarities in terms of pathology, it could be questioned if these results can be transferred to rotator cuff tendinopathy. The study "Does adding an eccentric training program to rehabilitation of patients with subacromial impingement result in better outcome? A randomized, clinical trial" examined the influence of a traditional rotator cuff training program whether or not combined with eccentric training on pain, function and isometric force.

Reference List

1. Almekinders LC. Impingement syndrome. *Clin Sports Med* 2001;20:491-504.
2. Almekinders LC, Weinhold PS, Maffulli N. Compression etiology in tendinopathy. *Clin Sports Med* 2003;22:703-710.
3. Anderson VB, Wee E. Impaired joint proprioception at higher shoulder elevations in chronic rotator cuff pathology. *Arch Phys Med Rehabil* 2011;92:1146-1151.
4. Atalar H, Yilmaz C, Polat O, Selek H, Uras I, Yanik B. Restricted scapular mobility during arm abduction: implications for impingement syndrome. *Acta Orthop Belg* 2009;75:19-24.
5. Bagg SD, Forrest WJ. A biomechanical analysis of scapular rotation during arm abduction in the scapular plane. *Am J Phys Med Rehabil* 1988;67:238-245.
6. Baltaci G, Tunay VB. Isokinetic performance at diagonal pattern and shoulder mobility in elite overhead athletes. *Scand J Med Sci Sports* 2004;14:231-238.
7. 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;30:126-137.
8. Bernhardsson S, Klintberg IH, Wendt GK. Evaluation of an exercise concept focusing on eccentric strength training of the rotator cuff for patients with subacromial impingement syndrome. *Clin Rehabil* 2011;25:69-78.
9. Bigliani LU, Ticker JB, Flatow EL, Soslowsky LJ, Mow VC. The relationship of acromial architecture to rotator cuff disease. *Clin Sports Med* 1991;10:823-838.
10. Borich MR, Bright JM, Lorello DJ, Cieminski CJ, Buisman T, Ludewig PM. Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. *J Orthop Sports Phys Ther* 2006;36:926-934.
11. Borsa PA, Dover GC, Wilk KE, Reinold MM. Glenohumeral range of motion and stiffness in professional baseball pitchers. *Med Sci Sports Exerc* 2006;38:21-26.
12. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. *Sports Med* 2008;38:17-36.
13. Borstad JD, Szucs K, Navalgund A. Scapula kinematic alterations following a modified push-up plus task. *Hum Mov Sci* 2009;28:738-751.
14. Brox JI, Roe C, Saugen E, Vollestad NK. Isometric abduction muscle activation in patients with rotator tendinosis of the shoulder. *Arch Phys Med Rehabil* 1997;78:1260-1267.
15. Brox JI, Gjengedal E, Uppheim G et al. Arthroscopic surgery versus supervised exercises in patients with rotator cuff disease (stage II impingement syndrome): a prospective, randomized, controlled study in 125 patients with a 2 1/2-year follow-up. *J Shoulder Elbow Surg* 1999;8:102-111.
16. Brox JI, Staff PH, Ljunggren AE, Brevik JI. Arthroscopic surgery compared with supervised exercises in patients with rotator cuff disease (stage II impingement syndrome). *BMJ* 1993;307:899-903.
17. Burkhart SS, Esch JC, Jolson RS. The rotator crescent and rotator cable: an anatomic description of the shoulder's "suspension bridge". *Arthroscopy* 1993;9:611-616.
18. 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;19:641-661.
19. Camargo PR, Avila MA, Alburquerque-Sendin F, Asso NA, Hashimoto LH, Salvini TF. Eccentric training for shoulder abductors improves pain, function and isokinetic performance in subjects with shoulder impingement syndrome: a case series. *Rev Bras Fisioter* 2011.
20. Chen SK, Simonian PT, Wickiewicz TL, Otis JC, Warren RF. Radiographic evaluation of glenohumeral kinematics: a muscle fatigue model. *J Shoulder Elbow Surg* 1999;8:49-52.
21. Chester R, Smith TO, Hooper L, Dixon J. The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: a systematic review of electromyographic studies. *BMC Musculoskelet Disord* 2010;11:45.

22. Chopp JN, O'Neill JM, Hurley K, Dickerson CR. Superior humeral head migration occurs after a protocol designed to fatigue the rotator cuff: a radiographic analysis. *J Shoulder Elbow Surg* 2010;19:1137-1144.
23. Clark J, Sidles JA, Matsen FA. The relationship of the glenohumeral joint capsule to the rotator cuff. *Clin Orthop Relat Res* 1990;29-34.
24. 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;28:3-14.
25. Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. *Scand J Med Sci Sports* 2007;17:25-33.
26. Cools AM, Dewitte V, Lanszweert F et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? *Am J Sports Med* 2007;35:1744-1751.
27. Cools AM, Johansson FR, Cagnie B, Cambier D, Witvrouw E. Stretching the posterior shoulder structures in subjects with internal rotation deficit: comparison of two stretching techniques. *Shoulder and Elbow* 2012;4:56-63.
28. Cools AM, Johansson FR, Cambier DC, Velde AV, Palmans T, Witvrouw EE. Descriptive profile of scapulothoracic position, strength and flexibility variables in adolescent elite tennis players. *Br J Sports Med* 2010;44:678-684.
29. Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. *Br J Sports Med* 2004;38:64-68.
30. Cools AM, Witvrouw EE, Mahieu NN, Danneels LA. Isokinetic Scapular Muscle Performance in Overhead Athletes With and Without Impingement Symptoms. *J Athl Train* 2005;40:104-110.
31. Curtis AS, Burbank KM, Tierney JJ, Scheller AD, Curran AR. The insertional footprint of the rotator cuff: an anatomic study. *Arthroscopy* 2006;22:609.
32. Dark A, Ginn KA, Halaki M. Shoulder muscle recruitment patterns during commonly used rotator cuff exercises: an electromyographic study. *Phys Ther* 2007;87:1039-1046.
33. Decker MJ, Tokish JM, Ellis HB, Torry MR, Hawkins RJ. Subscapularis muscle activity during selected rehabilitation exercises. *Am J Sports Med* 2003;31:126-134.
34. Diederichsen LP, Norregaard J, Dyhre-Poulsen P et al. The activity pattern of shoulder muscles in subjects with and without subacromial impingement. *J Electromyogr Kinesiol* 2009;19:789-799.
35. Dorrestijn O, Stevens M, Winters JC, van der Meer K, Diercks RL. Conservative or surgical treatment for subacromial impingement syndrome? A systematic review. *J Shoulder Elbow Surg* 2009;18:652-660.
36. Ebaugh DD, McClure PW, Karduna AR. Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. *J Electromyogr Kinesiol* 2006;16:224-235.
37. Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. *Br J Sports Med* 2010;44:319-327.
38. Ellenbecker TS, Roetert EP, Bailie DS, Davies GJ, Brown SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Med Sci Sports Exerc* 2002;34:2052-2056.
39. Endo K, Ikata T, Katoh S, Takeda Y. Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome. *J Orthop Sci* 2001;6:3-10.
40. Flatow EL, Soslowsky LJ, Ticker JB et al. Excursion of the rotator cuff under the acromion. Patterns of subacromial contact. *Am J Sports Med* 1994;22:779-788.
41. Fleming JA, Seitz AL, Ebaugh DD. Exercise protocol for the treatment of rotator cuff impingement syndrome. *J Athl Train* 2010;45:483-485.

42. Gill TJ, McIrvin E, Kocher MS, Homa K, Mair SD, Hawkins RJ. The relative importance of acromial morphology and age with respect to rotator cuff pathology. *J Shoulder Elbow Surg* 2002;11:327-330.
43. Graichen H, Bonel H, Stammberger T et al. Three-dimensional analysis of the width of the subacromial space in healthy subjects and patients with impingement syndrome. *Am J Roentgenol* 1999;172:1081-1086.
44. Graichen H, Stammberger T, Bonel H et al. Magnetic resonance-based motion analysis of the shoulder during elevation. *Clin Orthop Relat Res* 2000;154-163.
45. Green S, Buchbinder R, Hetrick SE. Physiotherapy interventions for shoulder pain (Review). The Cochrane Library [3]. 2008.
Ref Type: Journal (Full)
46. Haahr JP, Andersen JH. Exercises may be as efficient as subacromial decompression in patients with subacromial stage II impingement: 4-8-years' follow-up in a prospective, randomized study. *Scand J Rheumatol* 2006;35:224-228.
47. Haahr JP, Ostergaard S, Dalsgaard J et al. Exercises versus arthroscopic decompression in patients with subacromial impingement: a randomised, controlled study in 90 cases with a one year follow up. *Ann Rheum Dis* 2005;64:760-764.
48. Harryman DT, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA. Translation of the humeral head on the glenoid with passive glenohumeral motion. *J Bone Joint Surg Am* 1990;72:1334-1343.
49. Hashimoto T, Nobuhara K, Hamada T. Pathologic evidence of degeneration as a primary cause of rotator cuff tear. *Clin Orthop Relat Res* 2003;111-120.
50. Hebert LJ, Moffet H, McFadyen BJ, Dionne CE. Scapular behavior in shoulder impingement syndrome. *Arch Phys Med Rehabil* 2002;83:60-69.
51. Huang CY, Wang VM, Pawluk RJ et al. Inhomogeneous mechanical behavior of the human supraspinatus tendon under uniaxial loading. *J Orthop Res* 2005;23:924-930.
52. Hughes PC, Green RA, Taylor NF. Measurement of subacromial impingement of the rotator cuff. *J Sci Med Sport* 2012;15:2-7.
53. Johnson GR, Pandyan AD. The activity in the three regions of the trapezius under controlled loading conditions--an experimental and modelling study. *Clin Biomech (Bristol , Avon)* 2005;20:155-161.
54. Jonsson P, Wahlstrom P, Ohberg L, Alfredson H. Eccentric training in chronic painful impingement syndrome of the shoulder: results of a pilot study. *Knee Surg Sports Traumatol Arthrosc* 2006;14:76-81.
55. Kelly SM, Wrightson PA, Meads CA. Clinical outcomes of exercise in the management of subacromial impingement syndrome: a systematic review. *Clin Rehabil* 2010;24:99-109.
56. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med* 1998;26:325-337.
57. Kuhn JE. Exercise in the treatment of rotator cuff impingement: A systematic review and a synthesized evidence-based rehabilitation protocol. *J Shoulder Elbow Surg* 2008.
58. Langberg H, Ellingsgaard H, Madsen T et al. Eccentric rehabilitation exercise increases peritendinous type I collagen synthesis in humans with Achilles tendinosis. *Scand J Med Sci Sports* 2007;17:61-66.
59. Laudner KG, Moline MT, Meister K. The relationship between forward scapular posture and posterior shoulder tightness among baseball players. *Am J Sports Med* 2010;38:2106-2112.
60. Laudner KG, Sipes RC, Wilson JT. The acute effects of sleeper stretches on shoulder range of motion. *J Athl Train* 2008;43:359-363.
61. Leong HT, Tsui S, Ying M, Leung VY, Fu SN. Ultrasound measurements on acromio-humeral distance and supraspinatus tendon thickness: Test-retest reliability and correlations with shoulder rotational strengths. *J Sci Med Sport* 2011.
62. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther* 2000;80:276-291.

63. Ludewig PM, Cook TM. Translations of the humerus in persons with shoulder impingement symptoms. *J Orthop Sports Phys Ther* 2002;32:248-259.
64. Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. *Am J Sports Med* 2004;32:484-493.
65. Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF. Motion of the shoulder complex during multiplanar humeral elevation. *J Bone Joint Surg Am* 2009;91:378-389.
66. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther* 2009;39:90-104.
67. Luime JJ, Koes BW, Hendriksen IJ et al. Prevalence and incidence of shoulder pain in the general population; a systematic review. *Scand J Rheumatol* 2004;33:73-81.
68. 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;29:574-583.
69. MacDermid JC, Ramos J, Drosdowech D, Faber K, Patterson S. The impact of rotator cuff pathology on isometric and isokinetic strength, function, and quality of life. *J Shoulder Elbow Surg* 2004;13:593-598.
70. Machner A, Merk H, Becker R, Rohkohl K, Wissel H, Pap G. Kinesthetic sense of the shoulder in patients with impingement syndrome. *Acta Orthop Scand* 2003;74:85-88.
71. Mahieu NN, McNair P, Cools A, D'Haen C, Vandermeulen K, Witvrouw E. Effect of eccentric training on the plantar flexor muscle-tendon tissue properties. *Med Sci Sports Exerc* 2008;40:117-123.
72. Manske RC, Meschke M, Porter A, Schmitt B, Reiman M. A randomized controlled single-blinded comparison of stretching versus stretching and joint mobilization for posterior shoulder tightness measured by internal rotation motion loss. *Sports Health: A Multidisciplinary Approach* 2010;2:94-100.
73. McClure P, Balaicuis J, Heiland D, Broersma ME, Thorndike CK, Wood A. A randomized controlled comparison of stretching procedures for posterior shoulder tightness. *J Orthop Sports Phys Ther* 2007;37:108-114.
74. McClure PW, Bialker J, Neff N, Williams G, Karduna A. Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program. *Phys Ther* 2004;84:832-848.
75. McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. *Physical Therapy* 2006;86:1075-1090.
76. McCully SP, Suprak DN, Kosek P, Karduna AR. Suprascapular nerve block results in a compensatory increase in deltoid muscle activity. *J Biomech* 2007;40:1839-1846.
77. McMullen J, Uhl TL. A kinetic chain approach for shoulder rehabilitation. *Journal of Athletic Training* 2000;35:329-337.
78. McQuade KJ, Dawson J, Smidt GL. Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. *J Orthop Sports Phys Ther* 1998;28:74-80.
79. Meister K. Injuries to the shoulder in the throwing athlete. Part one: Biomechanics/pathophysiology/classification of injury. *Am J Sports Med* 2000;28:265-275.
80. Moore SD, Laudner KG, McLoda TA, Shaffer MA. The immediate effects of muscle energy technique on posterior shoulder tightness: a randomized controlled trial. *J Orthop Sports Phys Ther* 2011;41:400-407.
81. Myers JB, Hwang JH, Pasquale MR, Blackburn JT, Lephart SM. Rotator cuff coactivation ratios in participants with subacromial impingement syndrome. *J Sci Med Sport* 2009;12:603-608.
82. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med* 2006;34:385-391.

83. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Scapular position and orientation in throwing athletes. *Am J Sports Med* 2005;33:263-271.
84. Myers JB, Lephart SM. The Role of the Sensorimotor System in the Athletic Shoulder. *J Athl Train* 2000;35:351-363.
85. Neer CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder. 1972. *J Bone Joint Surg Am* 2005;87:1399.
86. Neer CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *J Bone Joint Surg Am* 1972;54:41-50.
87. Ohberg L, Lorentzon R, Alfredson H. Eccentric training in patients with chronic Achilles tendinosis: normalised tendon structure and decreased thickness at follow up. *Br J Sports Med* 2004;38:8-11.
88. Oyama S, Myers JB, Wassinger CA, Daniel RR, Lephart SM. Asymmetric resting scapular posture in healthy overhead athletes. *J Athl Train* 2008;43:565-570.
89. Parsons IM, Apreleva M, Fu FH, Woo SL. The effect of rotator cuff tears on reaction forces at the glenohumeral joint. *J Orthop Res* 2002;20:439-446.
90. Pascarelli EF, Hsu YP. Understanding work-related upper extremity disorders: clinical findings in 485 computer users, musicians, and others. *J Occup Rehabil* 2001;11:1-21.
91. Picavet HS, Schouten JS. Musculoskeletal pain in the Netherlands: prevalences, consequences and risk groups, the DMC(3)-study. *Pain* 2003;102:167-178.
92. Porterfield JA, DeRosa C. Mechanical shoulder disorders. Perspectives in functional anatomy. 2004. Elsevier Science.
Ref Type: Serial (Book,Monograph)
93. Pribicevic M, Pollard H, Bonello R. An epidemiologic survey of shoulder pain in chiropractic practice in australia. *J Manipulative Physiol Ther* 2009;32:107-117.
94. Reddy AS. Electromyographic analysis of the deltoid and rot tor cuff muscles in persons with subacromial impingement. *Journal of shoulder and elbow surgery* 2000;9:519.
95. Reinold MM, Escamilla RF, Wilk KE. Current concepts in the scientific and clinical rationale behind exercises for glenohumeral and scapulothoracic musculature. *J Orthop Sports Phys Ther* 2009;39:105-117.
96. Reinold MM, Macrina LC, Wilk KE et al. Electromyographic analysis of the supraspinatus and deltoid muscles during 3 common rehabilitation exercises. *J Athl Train* 2007;42:464-469.
97. Riemann BL, Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. *J Athl Train* 2002;37:71-79.
98. Riemann BL, Witt J, Davies GJ. Glenohumeral joint rotation range of motion in competitive swimmers. *J Sports Sci* 2011;29:1191-1199.
99. Royer PJ, Kane EJ, Parks KE et al. Fluoroscopic assessment of rotator cuff fatigue on glenohumeral arthrokinematics in shoulder impingement syndrome. *J Shoulder Elbow Surg* 2009;18:968-975.
100. Safran MR, Borsa PA, Lephart SM, Fu FH, Warner JJ. Shoulder proprioception in baseball pitchers. *J Shoulder Elbow Surg* 2001;10:438-444.
101. Seitz AL, McClure PW, Finucane S, Boardman III DN, Michener LA. Mechanisms of rotator cuff tendinopathy: Intrinsic, extrinsic, or both? *Clinical Biomechanics* 2011;26:1-12.
102. Seitz AL, McClure PW, Lynch SS, Ketchum JM, Michener LA. Effects of scapular dyskinesis and scapular assistance test on subacromial space during static arm elevation. *J Shoulder Elbow Surg* 2011.
103. Senbursa G, Baltaci G, Atay A. Comparison of conservative treatment with and without manual physical therapy for patients with shoulder impingement syndrome: a prospective, randomized clinical trial. *Knee Surg Sports Traumatol Arthrosc* 2007;15:915-921.
104. Silva RT, Hartmann LG, Laurino CF, Bilo JP. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. *Br J Sports Med* 2010;44:407-410.

105. 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.
106. Soslowsky LJ, Thomopoulos S, Esmail A et al. Rotator cuff tendinosis in an animal model: role of extrinsic and overuse factors. *Ann Biomed Eng* 2002;30:1057-1063.
107. Struyf F, Nijs J, Baeyens JP, Mottram S, Meeusen R. Scapular positioning and movement in unimpaired shoulders, shoulder impingement syndrome, and glenohumeral instability. *Scand J Med Sci Sports* 2011;21:352-358.
108. Teyhen DS, Miller JM, Middag TR, Kane EJ. Rotator cuff fatigue and glenohumeral kinematics in participants without shoulder dysfunction. *J Athl Train* 2008;43:352-358.
109. Thigpen CA, Padua DA, Morgan N, Kreps C, Karas SG. Scapular kinematics during supraspinatus rehabilitation exercise: a comparison of full-can versus empty-can techniques. *Am J Sports Med* 2006;34:644-652.
110. Thomas SJ, Swanik CB, Higginson JS et al. A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. *J Shoulder Elbow Surg* 2011;20:708-716.
111. Thomas SJ, Swanik KA, Swanik C, Huxel KC. Glenohumeral rotation and scapular position adaptations after a single high school female sports season. *J Athl Train* 2009;44:230-237.
112. Thomas SJ, Swanik KA, Swanik CB, Kelly JD. Internal rotation deficits affect scapular positioning in baseball players. *Clin Orthop Relat Res* 2010;468:1551-1557.
113. Tyler TF, Nahow RC, Nicholas SJ, McHugh MP. Quantifying shoulder rotation weakness in patients with shoulder impingement. *J Shoulder Elbow Surg* 2005;14:570-574.
114. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med* 2000;28:668-673.
115. Tyler TF, Roy T, Nicholas SJ, Gleim GW. Reliability and validity of a new method of measuring posterior shoulder tightness. *J Orthop Sports Phys Ther* 1999;29:262-269.
116. Van Cingel R, Kleinrensink G, Stoeckart R, Aufdemkampe G, De Bie R, Kuipers H. Strength values of shoulder internal and external rotators in elite volleyball players. *J sport rehabil* 2006;15:237-245.
117. Walther M, Werner A, Stahlschmidt T, Woelfel R, Gohlke F. The subacromial impingement syndrome of the shoulder treated by conventional physiotherapy, self-training, and a shoulder brace: results of a prospective, randomized study. *J Shoulder Elbow Surg* 2004;13:417-423.
118. Warner JJ, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *Am J Sports Med* 1990;18:366-375.
119. Werner A, Walther M, Ilg A, Stahlschmidt T, Gohlke F. Self-training versus conventional physiotherapy in subacromial impingement syndrome. *Z Orthop Ihre Grenzgeb* 2002;140:375-380.
120. Wilk KE, Macrina LC, Fleisig GS et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med* 2011;39:329-335.
121. Wilk KE, Obma P, Simpson CD, Cain EL, Dugas JR, Andrews JR. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther* 2009;39:38-54.
122. Worland RL, Lee D, Orozco CG, SozaRex F, Keenan J. Correlation of age, acromial morphology, and rotator cuff tear pathology diagnosed by ultrasound in asymptomatic patients. *J South Orthop Assoc* 2003;12:23-26.
123. Zattara M, Bouisset S. Posturo-kinetic organisation during the early phase of voluntary upper limb movement. 1. Normal subjects. *J Neurol Neurosurg Psychiatry* 1988;51:956-965.

CHAPTER 1| THE IMPACT OF ROTATOR CUFF TENDINOPATHY ON PROPRIOCEPTION, MEASURING FORCE SENSATION

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Chapter 1

ABSTRACT

Background The impact of rotator cuff tendinopathy and related impingement on proprioception is not well understood. Numerous quantitative and qualitative changes in shoulder muscles have been shown in patients with rotator cuff tendinopathy. These findings suggest that control of force might be affected. This investigation wants to evaluate force sensation, a submodality of proprioception, in patients with rotator cuff tendinopathy.

Methods Thirty-six patients with rotator cuff tendinopathy and 30 matched healthy subjects performed force reproduction tests to isometric external and internal rotation to investigate how accurate they could reproduce a fixed target (50% MVC). Relative error, constant error and force steadiness were calculated to evaluate respectively magnitude of error made during the test, direction of this error (overshoot or undershoot) and fluctuations of produced forces.

Results Patients significantly overshoot the target (Mean= 6.04% of target) while healthy subjects underestimate the target (Mean= -5.76% of target). Relative error and force steadiness are similar in patients with rotator cuff tendinopathy and healthy subjects. Force reproduction tests, as executed in this study, were found to be highly reliable (ICC 0.849 and 0.909). Errors were significantly larger during external rotation tests, compared to internal rotation.

Conclusion Patients overestimate the target during force reproduction tests. This should be taken into account in the rehabilitation of patients with rotator cuff tendinopathy. Precision of force sensation and steadiness of force exertion however remains unaltered. This might indicate control of muscle force is preserved.

Level of Evidence Basic Science Study, Kinesiology Study

Keywords Shoulder, rotator cuff, tendinopathy, proprioception, force reproduction, force steadiness, force sensation

INTRODUCTION

Tendinopathy of the rotator cuff shows high prevalence in the population and can be the source of considerable pain and disability.[8,23] Patients with rotator cuff tendinopathy show numerous quantitative and qualitative changes in specific shoulder muscles. Quantitative impairment of rotator cuff muscle force was demonstrated in patients with impingement. Larger deficits in external rotation force than internal rotation force occur, resulting in muscular imbalance.[23,34]

Quality of force production was also found to be changed in patients with impingement. A bilateral decline in time to peak torque of the internal rotators was shown in patients by Matiello-Rosa et al.[25] During elevation bilateral deficits in muscle contraction parameters were shown in patients. Acceleration time and time to peak torque are delayed, total work and power are reduced and peak torque has decreased in subjects with subacromial impingement when compared to asymptomatic subjects.[5]

Neuromuscular dysfunction is expressed in the different muscle recruitment patterns during elevation and external rotation, shown in patients with subacromial impingement. Common findings include decreased activity in the rotator cuff muscles and serratus anterior and increased activity in the middle deltoid and the upper trapezius.[5,7,12,22,28]

Good neuromuscular control depends on adequate proprioceptive information.[14] Investigations on proprioception in patients with rotator cuff tendinopathy are limited. Machner et al. showed impaired kinaesthesia, defined as the perception of movement, in the affected side compared to the contralateral side in subjects with subacromial impingement.[24] Safran et al. also demonstrated disturbed kinaesthesia in throwers with rotator cuff tendinopathy and suggested that increased nociceptor activity in the painful shoulder overrides proprioceptive input.[29]

Proprioception has three submodalities. Besides kinaesthesia and joint position sense, force sensation is an important feature for good neuromuscular control. It is defined as the ability to appreciate and interpret force applied to or generated within a joint.[26] The level to which each muscle is activated during movement plays an important role in coordinating movement. Many organs are thought to encode force sensation including Golgi tendon organs and muscle spindles as well as central mechanisms.[4,14] Dover et al. developed a force reproduction test to measure force sensation of the shoulder internal and external rotators using an isokinetic device and showed high reliability and reproducibility of this test.[13]

Considering the above described quantitative and qualitative changes in rotator cuff muscles and the related neuromuscular recruitment pattern alterations, it is possible force sensation has changed in patients with rotator cuff tendinopathy. The rotator cuff plays an important role in opposing the superior translation force of the deltoid.[32,33] A lack of good control of muscle force could compromise dynamic stability of the shoulder joint resulting in altered glenohumeral kinematics. Anterosuperior translation of the humerus has already been demonstrated in patients with rotator cuff tendinopathy.[21]

The purpose of this study is to measure the accuracy of force sensation in the internal and external shoulder rotators in patients with rotator cuff tendinopathy with an isometric force reproduction test. Magnitude of the error made during the force reproduction test, whether subjects over- or underestimated force and the extent to which subjects could exert a continuous force without fluctuations (i.e., force steadiness) were of interest. It was hypothesized force sensation would be different in the affected compared to the non-affected shoulder and would differ between patients and asymptomatic subjects. The influence of age and pain were of interest.

MATERIALS AND METHODS

Subjects

Sample size was estimated based on variability of pilot data from force reproduction tests (mean group A: 19,01; mean group B: 12,02; standard deviation: 4,5). SPSS Sample Power 3 was used. A probability level of α=0.05 and a statistical power of p=0.80 required 30 subjects in each group. Thirty-six subjects with unilateral rotator cuff tendinopathy were recruited by a specialized shoulder surgeon at Ghent University Hospital (Ghent, Belgium). The inclusion criteria were: unilateral pain for at least 3 months in the anterolateral region of the shoulder, pain score 3 or more out of 10 on Visual Analogue Scale, painful arc, 2 out of 3 impingement tests positive (Hawkins, Jobe and/or Neer), 2 out of 4 resistance tests painful (full can abduction at 90°, resisted abduction at 0°, resisted external or internal rotation) and pain with palpation of the supraspinatus and/ or infraspinatus tendon insertion.[9] The exclusion criteria were: demonstration of partial or full ruptures of the rotator cuff by technical investigation (ultrasound or MRI), history of shoulder surgery, fracture or dislocation, traumatic onset of the pain, osteoarthritis, severe glenohumeral instability or scapular dyskinesia. Patients with concomitant disorders, such as cervical pathology or systemic musculoskeletal disease, were also excluded from the study. No physical therapy nor corticosteroid injections could have been received within 2 months prior to the study. Demographics of the patient group are presented in table 1. There were 22 female and 14 male patients. All but one was right-hand dominant. Thirty-one patients had pain in their dominant shoulder, 5 in their non-dominant shoulder.

To be included in the asymptomatic group, subjects could not perform overhead sports nor any other upper limb force training for more than 5 hours a week and could not have been operated at their shoulder or neck in the past. No one of the asymptomatic group had shoulder pain during the year previous to the investigation. Thirty subjects were included (Table 1): 15 female and 15 male. All but one was right handed. They were matched for age to the symptomatic group.

	Patients		Healthy subjects	
	Mean	**SD**	**Mean**	**SD**
Age	43,13 (range 23-68)	±13,8	41,45 (range 21-65)	±13,1
Height	169,61	±9,40	171,21	±8,13
Weight	72,17	±12,51	69,10	±12,27

Table 1. Demographics (SD= standard deviation, age in years, height in cm, weight in kg)

The Committee on Ethics of Ghent University approved the study (Belgian registration number: B67020084347) and informed consent was obtained from each subject. This study is part of a larger study, registered on ClinicalTrials.gov (NCT00782522).

Instrumentation and procedures

All tests were completed at the laboratory of the Department of Rehabilitation Science and Physiotherapy of Ghent University. Painful and healthy arms of the patients were randomly chosen to start evaluation as was the order of internal and external rotation tests. In asymptomatic subjects only the dominant arm was tested. Force reproduction was retested in this group to look at test-retest reliability. Testing sessions were separated by 6 weeks. The order of external and internal rotation was the same at each testing session.

An isokinetic dynamometer (Biodex Multijoint System 3, Biodex Medical Systems, Inc., Shirley, NY) was used to investigate force sensation with a force reproduction test.[13] Figure 1 illustrates the experimental setup. Subjects were seated with the upper arm at 45°of elevation in the scapular plane and the elbow flexed 90°. The olecranon was aligned over the rotation axis. Because of technical issues, the lower arm was positioned vertically so gravity force was zero. Subjects grasped the handle of the shoulder-elbow attachment in a neutral position between pro- and supination.

Figure 1. Experimental setup

The dynamometer was set to gather data in the isometric mode. Maximal voluntary isometric contraction (MVIC) was obtained first. Three trials of 5 seconds with an equal time of rest in between were performed. Coefficient of variance over the three trials was not allowed to be higher than 15%.[10] After the MVIC test a resting period of 5 minutes was provided. The highest peak torque (PT) of the three trials was marked. Target for matching of force was set at 50% of that PT and a line was drawn at this target in the computer screen.[11,13,19] Previous authors suggested that using 50% of MVIC generates less error with reproduction.[19] Subjects were asked to produce force until the line of their force coincided with the target. Three trials were performed with visual feedback. After this, subjects were asked to close their eyes and produce the same amount of force for 3 more trials of 5 seconds. Subjects scored the pain they felt during the test on a VAS (0-10).

Data reduction

Raw data were extracted from the Biodex as text files. Means and standard deviations (SD) were calculated using MATLAB Version 7.8 (R2009a) (Mathworks Inc., Natick, MA). To measure the accuracy of force sensation, relative and constant error scores were chosen. The middle three seconds of each trial were used for analysis.

First, MATLAB calculated the deviation of the force exerted by the subject from the target, at each point in time, ignoring positive (overshoot) and negative (undershoot) values. Then, mean deviation was calculated over three trials. Finally, this error was expressed relative to the target to represent **relative error** (RE) (Table 2). Like this, comparison between subjects is allowed, as

RE represents the magnitude of error, proportional to their target, which depends on their maximal isometric force. .

To express direction of mismatch, **constant error** (CE) was calculated (Table 2). Mean error over the three trials was calculated by subtracting the target from the mean force produced by the subjects. This was also expressed as a proportion of the target. If this constant error score is positive, it means the target was overestimated and vice versa.

Steadiness of force reproduction is represented by the **coefficient of variation** (CV) (Table 2). This was calculated by averaging the SD over three trials. CV was expressed as a proportion of the mean force produced during the trials and like this, represents the extent to which subjects are able to produce a continuous force with minimal fluctuations.

RE	(|error trial 1|+ |error trial 2|+ |error trial 3|) /3 Target
CE	(error trial 1 + error trial 2 + error trial 3) /3 Target
CV	(SD trial 1 + SD trial 2 + SD trial 3) / 3 (Mean trial 1+ Mean trial 2 + Mean trial 3) /3

Table 2. Formulas for calculation of Relative Error (RE), Constant Error (CE) and Coefficient of Variance (CV) (SD= standard deviation)

Statistical analysis

Data were analyzed using PASW Statistics 18 (SPSS Inc., Chicago, IL). A level of 5% was used to determine significant differences. Shapiro-Wilk test showed normal distribution of all data.

Test-retest intraclass correlation coefficients (ICC) were calculated for mean internal and external rotation force generated during force reproduction tests in asymptomatic subjects. Standard error of measurement (SEM) was calculated with the formula SD x √1-ICC where SD was the standard deviation of mean force during the tests.

For each dependent variable (RE, CE and CV), a general linear model (GLM) univariate analysis of variance (ANOVA) test was constructed with "group" (2 levels: patient and healthy) or "side" (2 levels: painful and healthy side) and "direction" (2 levels: internal and external rotation) as fixed factors, and age and pain as cofactors. Post-hoc test were performed with correction for multiple comparisons (Bonferroni).

RESULTS

ICC of force reproduction tests

ICC showed high reliability between the two testing sessions for internal (Cronbach's alfa= 0.849) as well as for external rotation (α= 0.909) force reproduction testing in asymptomatic subjects. SEM was 2.34N for the internal rotation force reproduction test and 1.97N for the external rotation force reproduction test.

Patients compared to healthy subjects

Results of comparing force sensation between patients and healthy subjects are presented in the left part of figure 2. There was no significant difference in RE between groups. (F=1.915, p=0.17). RE did show significant difference between internal and external rotation (F=6.980, p=0.01). Post hoc tests revealed higher errors during the external rotation tests (18.19% of the target) than during the internal rotation (13.69% of the target). CE was significantly different between groups (F=5.127, p=0.026). Post-hoc tests showed that patients overestimate the target (6.04% of target) while asymptomatic people rather underestimate the target (-5.76% of target). CE was not different between both directions (F=0.291, p=0,59).
CV was not significantly different between patients and healthy subjects (F=0.508, p=0,478). CV was different between both directions of the test (F=7.048, p<0.01). Post hoc tests showed less smooth force production during external rotation force reproduction (11.52% of mean force) compared to the internal rotation force reproduction test (8.28% of mean force). There was no significant influence of the cofactors age and pain.

Painful side compared to healthy side in patients

Results of comparing force sensation at the painful shoulder compared to the healthy shoulder are presented in the right part of Figure 2. When analyzing RE, CE and CV of force reproduction in patients, there was no significant difference between painful and healthy side (F=0.090, p=0.77; F=0.975, p=0.33; F=0.540, p=0.46). Patients will not make larger errors with their painful shoulder and will not over- or underestimate their force differently in their painful side compared to their asymptomatic side. Smoothness of shoulder muscle contraction appears to be unaffected in the injured shoulder of patients compared to their asymptomatic side. RE was different between the internal and external rotation test (F=4.007, p=0.04) with a higher RE during the external rotation force reproduction test (18.76% of the target) compared to the internal rotation force reproduction test (14.68% of the target). CE was not different between both directions (F=1.107, p=0.30).

CV was significantly different between directions (F=10.157, p=0.002). Post-hoc tests revealed less steadiness of force during external rotation (11.98% of mean force) when compared to internal rotation (8.04% of mean force). Age and pain showed no significant influence.

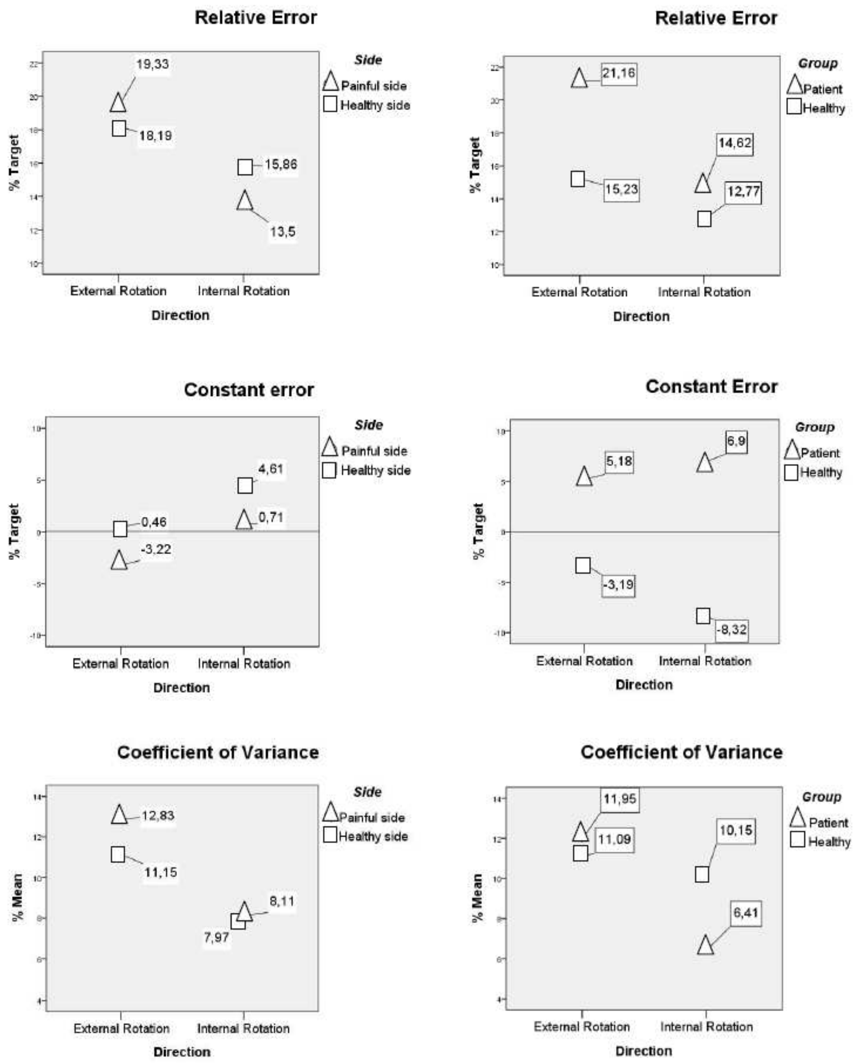

Figure 2. Mean error scores for internal and external rotation force reproduction tests in the painful compared to healthy side in patients (left) and in patients compared to healthy subjects (right).

DISCUSSION

The key finding of this investigation is that, regardless of direction of the test, patients overshoot the target compared to asymptomatic subjects. However, no difference was found between the painful and healthy side in patients. Overestimation of muscle forces, required for a given task, might further aggravate the symptoms and should be taken into account during rehabilitation.

As to magnitude of error and steadiness of isometric force production, no differences were found between the painful and healthy side of patients, nor between patients and asymptomatic subjects. Good control of force is preserved in patients with rotator cuff tendinopathy.

This is the first study investigating force reproduction in patients with rotator cuff tendinopathy. Previously, asymptomatic individuals have been shown to overrate effort during force matching tasks after experimentally inducing pain, fatigue and/or muscle damage in the tested limb.[3,18,27,35,36]

Research on how musculoskeletal pathology changes force sensation is rather scarce. Descarreaux et al. investigated isometric lumbar flexion and extension force reproduction at 50 and 75% of MVC in patients with low back pain, compared to asymptomatic control subjects.[11] Patients were trained to reproduce the force within an error margin of 10% before the test was taken. The accuracy level of the test in patients was similar to that in control subjects. Pain, however, had an important influence on time to reach peak forces. The authors speculate patients possibly limit the rate of force development to avoid an increase of pain. Descarreaux et al. could not show overestimation by patients with low back pain, but the fact they were trained in advance to match the target gives a plausible explanation for this. Furthermore, accuracy level was calculated only by comparing peak force during the test with the target. Possibly, this is not a representative method for describing the error in reproducing the target.

Hortobagyi et al. examined quadriceps force accuracy and steadiness in patients with knee osteoarthritis.[15] Patients demonstrated less accuracy and steadiness than their asymptomatic peers for both concentric and eccentric isokinetic conditions. Corresponding with our results, the error in osteoarthritis patients also resulted from overshooting the target. No differences in accuracy, nor steadiness were found for the isometric condition.

No studies have investigated force sensation in patients with shoulder pathology. However, two studies were found that examined abduction force steadiness in patients with subacromial impingement syndrome. Consistent with our results on isometric external and internal rotation force steadiness, both studies showed preserved steadiness during isometric abduction of the shoulder.[2,6] Subjects were allowed to visually control the force they produced relative to the target so that force sensation was not tested in these studies. Bandholm et al. did find reduced steadiness during isometric abduction in asymptomatic subjects after experimentally inducing pain.[1] A possible explanation for this discrepancy is that induction of experimental pain does not reflect adaptations to chronic pain.

These data cannot point out the neurophysiologic origin of the observed differences. Force sensation arises mainly from a combination of sensation of tension by peripheral Golgi tendon organs and central sensation of effort.[4,14,17] Overestimation of force can possibly point at reduced sensitivity of proprioceptors. Muscle changes due to chronic pathology alters human Golgi tendon organ characteristics. A reduction in both muscle spindle and Golgi tendon organ size and numbers has been demonstrated after injury and disuse.[20,30] The discovery of a significant positive correlation between Golgi tendon organ firing rates and muscle fiber cross-sectional area by Spielmann and Stauffer also suggests that Golgi tendon organ function could be affected in chronic musculoskeletal conditions where muscle atrophy is evident.[31] Histological research of the deltoid and supraspinatus muscle by Irlenbusch et al. has shown changes in fast and slow twitch fibres in patients with impingement.[16] This could support the above described theory.
However, the fact that this deficit in force sensation is not different from the asymptomatic arm argues against this theory. Next to peripheral sensation of tension by Golgi tendon organs, there might be an important role for central sensation of effort. In this view, it is possible that force sensation depends on the power of the agonists. A more powerful muscle group provides a feeling of less effort than a weak muscle group. Possibly, the asymptomatic dominant arm induces a feeling of light effort whilst the non-dominant arm produces a feeling of more effort needed during force application. When the dominant arm is injured, which was the case in most of the patients, a feeling of larger effort is produced which could lead to overestimation of the target. Further research is necessary to confirm this.

Regardless of subject group, significant differences in force steadiness and magnitude of errors were noted between the two muscle groups tested. Starting position could be responsible for this. The external rotators were placed in a shortened position while the internal rotators were in a lengthened position.
The relationship between a muscle's length and its isometric tension generating capacity depends on the degree of overlap between its actine and myosine filaments. Muscle length is therefore capable of influencing force matching acuity. This could give an explanation for the larger relative error and the less steady force production during external rotation tests than during internal rotation tests. It is worth noting that, in the current study, both subject groups reported the external rotation force reproduction test as more difficult.

Dover and Powers could not demonstrate this difference between internal and external rotation force reproduction.[13] This can be explained on the basis of their error calculation method. They showed higher peak torques during maximal isometric internal rotation force tests compared to external rotation thus higher target forces during internal rotation force reproduction tests, but equal absolute errors during the force reproduction tests. This implies larger relative error scores during external rotation than during internal rotation force reproduction, which is nonetheless in line with the results of this study.

This study offers a new approach on the evaluation of force sensation, describing magnitude of error, direction of error and steadiness of produced forces. Future research should investigate the same parameters during concentric and eccentric internal and external rotation in patients with rotator cuff tendinopathy. Correlation between a muscle group's force and its ability to reproduce a target is of interest. Moreover it would be interesting to link force reproduction errors to electromyographic activity of shoulder muscles during the tests. This could provide insight into responsible mechanisms for overshooting the target.

CONCLUSION

The present study investigated the impact of rotator cuff tendinopathy on proprioception, measuring force sensation. It was shown that patients overestimate target forces and produce higher forces than needed in direction of external as well as internal rotation. Rehabilitation programs should take this finding into account. Precision of force sensation and steadiness of force exertion however remains unaltered. This might indicate control of muscle force is preserved. This study provides a new approach on evaluation of proprioception in shoulder patients. Further research is necessary to elaborate this.

Reference List

1. Bandholm T, Rasmussen L, Aagaard P, Diederichsen L, Jensen BR. Effects of experimental muscle pain on shoulder-abduction force steadiness and muscle activity in healthy subjects. Eur J Appl Physiol 2008; 6(102): 643-50. doi:10.1007/s00421-007-0642-1
2. Bandholm T, Rasmussen L, Aagaard P, Jensen BR, Diederichsen L. Force steadiness, muscle activity, and maximal muscle strength in subjects with subacromial impingement syndrome. Muscle Nerve 2006; 5(34): 631-9. doi: 10.1002/mus.20636
3. Cafarelli E. Force sensation in fresh and fatigued human skeletal muscle. Exerc Sport Sci Rev 1988(16): 139-68. doi:10.1249/00003677-198800160-00007
4. Cafarelli E. Peripheral contributions to the perception of effort. Med Sci Sports Exerc 1982; 5(14): 382-9. doi:10.1249/00005768-198205000-00013
5. Camargo PR, Avila MA, Asso NA, Salvini TF. Muscle performance during isokinetic concentric and eccentric abduction in subjects with subacromial impingement syndrome. Eur J Appl Physiol 2010; 3(109): 389-95. doi:10.1007/s00421-010-1365-2
6. Camargo PR, Avila MA, de Oliveira AB, Asso NA, Benze BG, de Fatima ST. Shoulder abduction torque steadiness is preserved in subacromial impingement syndrome. Eur J Appl Physiol 2009; 3(106): 381-7. doi:10.1007/s00421-009-1030-9
7. Chester R, Smith TO, Hooper L, Dixon J. The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: a systematic review of electromyographic studies. BMC Musculoskelet Disord 2010(11): 45. doi:10.1186/1471-2474-11-45
8. Chipchase LS, O'Connor DA, Costi JJ, Krishnan J. Shoulder impingement syndrome: preoperative health status. J Shoulder Elbow Surg 2000; 1(9): 12-5. doi:10.1016/S1058-2746(00)90003-X
9. Cools AM, Cambier D, Witvrouw EE. Screening the athlete's shoulder for impingement symptoms: a clinical reasoning algorithm for early detection of shoulder pathology. Br J Sports Med 2008; 8(42): 628-35. doi:10.1136/bjsm.2008.048074
10. Cools AM, Witvrouw EE, Danneels LA, Vanderstraeten GG, Cambier DC. Test-retest reproducibility of concentric strength values for shoulder girdle protraction and retraction using the Biodex isokinetic dynamometer. Isokinetics and Exercise Science 2002; 3(10): 129-36.
11. Descarreaux M, Blouin JS, Teasdale N. Force production parameters in patients with low back pain and healthy control study participants. Spine (Phila Pa 1976) 2004; 3(29): 311-7. doi: 00007632-200402010-00014
12. Diederichsen LP, Norregaard J, Dyhre-Poulsen P, Winther A, Tufekovic G, Bandholm Tet al. The activity pattern of shoulder muscles in subjects with and without subacromial impingement. J Electromyogr Kinesiol 2009; 5(19): 789-99. doi:10.1016/j.jelekin.2008.08.006
13. Dover G, Powers ME. Reliability of Joint Position Sense and Force-Reproduction Measures During Internal and External Rotation of the Shoulder. J Athl Train 2003; 4(38): 304-10.
14. Gandevia SC, Burke D. Does the Nervous System Depend on Kinesthetic Information to Control Natural Limb Movements. Behavioral and Brain Sciences 1992; 4(15): 614-32. doi:10.1017/CBO9780511529788.003
15. Hortobagyi T, Garry J, Holbert D, Devita P. Aberrations in the control of quadriceps muscle force in patients with knee osteoarthritis. Arthritis Rheum 2004; 4(51): 562-9. doi:10.1002/art.20545
16. Irlenbusch U, Gansen HK. Muscle biopsy investigations on neuromuscular insufficiency of the rotator cuff: a contribution to the functional impingement of the shoulder joint. J Shoulder Elbow Surg 2003; 5(12): 422-6. doi:10.1016/S1058274603000363
17. Jones LA. Role of central and peripheral signals in force sensation during fatigue. Exp Neurol 1983; 2(81): 497-503. doi:10.1016/0014-4886(83)90278-9
18. Jones LA, Hunter IW. Effect of fatigue on force sensation. Exp Neurol 1983; 3(81): 640-50. doi:10.1016/0014-4886(83)90332-1

19. Jones LA, Hunter IW. Force sensation in isometric contractions: a relative force effect. Brain Res 1982; 1(244): 186-9. doi:10.1016/0006-8993(82)90919-2
20. Jozsa L, Kannus P, Jarvinen TAH, Balint J, Jarvinen M. Number and morphology of mechanoreceptors in the myotendinous junction of paralysed human muscle. Journal of Pathology 1996; 2(178): 195-200. doi:10.1002/(SICI)1096-9896(199602)178:2
21. Ludewig PM, Cook TM. Translations of the humerus in persons with shoulder impingement symptoms. J Orthop Sports Phys Ther 2002; 6(32): 248-59.
22. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000; 3(80): 276-91.
23. MacDermid JC, Ramos J, Drosdowech D, Faber K, Patterson S. The impact of rotator cuff pathology on isometric and isokinetic strength, function, and quality of life. J Shoulder Elbow Surg 2004; 6(13): 593-8. doi:10.1016/S1058274604001247
24. Machner A, Merk H, Becker R, Rohkohl K, Wissel H, Pap G. Kinesthetic sense of the shoulder in patients with impingement syndrome. Acta Orthop Scand 2003; 1(74): 85-8. doi:10.1080/00016470310013716
25. Mattiello-Rosa SM, Camargo PR, Santos AA, Padua M, Reiff RB, Salvini TF. Abnormal isokinetic time-to-peak torque of the medial rotators of the shoulder in subjects with impingement syndrome. J Shoulder Elbow Surg 2008; 1 Suppl(17): 54S-60S. doi:10.1016/j.jse.2007.08.006
26. Myers JB, Lephart SM. The role of the sensorimotor system in the athletic shoulder. J Athl Train 2000; 3(35): 351-63.
27. Proske U, Gregory JE, Morgan DL, Percival P, Weerakkody NS, Canny BJ. Force matching errors following eccentric exercise. Hum Mov Sci 2004; 3-4(23): 365-78. doi:10.1016/j.humov.2004.08.012
28. Reddy AS, Mohr KJ, Pink MM, Jobe FW. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. J Shoulder Elbow Surg 2000; 6(9): 519-23.
29. Safran MR, Borsa PA, Lephart SM, Fu FH, Warner JJ. Shoulder proprioception in baseball pitchers. J Shoulder Elbow Surg 2001; 5(10): 438-44. doi:10.1067/mse.2001.118004
30. Scott JJA, Petit J, Davies P. The dynamic response of feline Golgi tendon organs during recovery from nerve injury. Neuroscience Letters 1996; 3(207): 179-82. doi:10.1016/0304-3940(96)12527-1
31. Spielmann JM, Stauffer EK. Morphological Observations of Motor Units Connected In-Series to Golgi Tendon Organs. Journal of Neurophysiology 1986; 1(55): 147-62.
32. Terrier A, Reist A, Vogel A, Farron A. Effect of supraspinatus deficiency on humerus translation and glenohumeral contact force during abduction. Clin Biomech (Bristol, Avon) 2007; 6(22): 645-51. doi:10.1016/j.clinbiomech.2007.01.015
33. Thompson WO, Debski RE, Boardman ND, III, Taskiran E, Warner JJ, Fu FHet al. A biomechanical analysis of rotator cuff deficiency in a cadaveric model. Am J Sports Med 1996; 3(24): 286-92. doi:10.1177/036354659602400307
34. Warner JJ, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. Am J Sports Med 1990; 4(18): 366-75. doi:10.1177/036354659001800406
35. Weerakkody NS, Percival P, Canny BJ, Morgan DL, Proske U. Force matching at the elbow joint is disturbed by muscle soreness. Somatosens Mot Res 2003; 1(20): 27-32. doi:10.1080/0899022031000083816
36. Weerakkody NS, Percival P, Morgan DL, Gregory JE, Proske U. Matching different levels of isometric torque in elbow flexor muscles after eccentric exercise. Experimental Brain Research 2003; 2(149): 141-50.

CHAPTER 2| SONOGRAPHIC EVALUATION OF THE ACROMIOHUMERAL DISTANCE IN ELITE AND RECREATIONAL FEMALE OVERHEAD ATHLETES.

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Chapter 2

ABSTRACT

Objective To compare the acromiohumeral distance (AHD) and the change of this distance during abduction between the dominant and non-dominant shoulders of healthy female overhead athletes and to compare AHD between elite and recreational female athletes.

Design Case-control study

Setting Laboratory, institutional

Independent Variables "side" (dominant - non-dominant), "group" (elite – recreational athletes) and "degree of abduction" (0 – 45 - 60°)

Participants Sixty-two female overhead athletes participated in this study: 29 elite handball players and 33 recreational overhead athletes of different sports disciplines (volleyball, water polo, squash and badminton).

Main outcome measures AHD was measured at 3 positions of abduction using ultrasound: at 0, 45 and 60° of abduction.

Results AHD measurements showed good test-retest reliability (ICCs between 0.88 and 0.92). In all overhead athletes, the AHD was significantly larger on the dominant side compared to the non-dominant side, at all positions of abduction (Mean difference=0.94±0.18mm). Significant reduction of the AHD during abduction occurred relative to the initial size at 0° of abduction, at both sides. When comparing elite and recreational athletes, the AHD was significantly larger in elite athletes (Mean difference=0.92±0.47mm). Moreover, significantly less reduction occurs during the first degrees of abduction (0°-45°) in elite athletes (9.37±2.17% reduction) compared to the recreational athletes (17.68±2.03% reduction).

Conclusions The AHD is larger on the dominant side compared to the non-dominant side and in elite female athletes compared to recreational female athletes. Moreover, less reduction of the AHD occurs in the elite athlete group during the first 45° of abduction.

Keywords Shoulder motion, shoulder injuries, ultrasound

INTRODUCTION

During overhead throwing, the shoulder acts like a funnel to transmit all forces collected in legs and trunk to the ball. Optimization of this process needs delicate balancing between mobility and stability. Moreover, smooth and coordinated movement in the glenohumeral and scapulothoracic joint is required to preserve subacromial space in order to allow optimal rotator cuff functioning. It is believed that when this balance is disturbed, the rotator cuff tendons are impinged between the coracoacromial arch and the humeral head.[1,2]

The overhead throwing shoulder has been shown to adapt to these high demands in a specific way.[3] Several studies have consistently reported changes in the mobility pattern of the glenohumeral joint of overhead throwing athletes. The dominant side shows increased external rotation mobility, combined with decreased internal rotation mobility compared to the non-dominant side.[4-6] This last phenomenon is called glenohumeral internal rotation deficit (GIRD) if the internal rotation is decreased for 20° or more compared to the non-dominant side.[7] GIRD has also been shown in patients with subacromial impingement and is believed to be part of the multifactorial etiology of rotator cuff tendinopathy.[8-10] Through increased anterior and superior translation of the humeral head, the loss of internal rotation could contribute to narrowing of the subacromial space.[11,12]

Next to the glenohumeral joint, the scapulothoracic joint also appears to be influenced by sports activity.[13] Comparing the resting position of both scapulae in overhead athletes shows the dominant scapula is more protracted, internally rotated and anteriorly tilted.[10,14] These scapular position alterations have also been found to result in diminished size of the subacromial space.[15,16] However, during active elevation, athletes show more upward rotation of the scapula on the dominant shoulder.[17,18] This rather suggests elevation of the acromion enlarging the subacromial space.[19]

Other adaptations shown in overhead athletes, like muscle imbalances of the rotator cuff and scapular muscles[20-23] and shortening of the pectoralis minor[18], are also able to influence the size of the subacromial space.

To our knowledge, no studies are available that describe the acromiohumeral distance (AHD), which is a two-dimensional (2D) measure for the size of the subacromial space, in the dominant and non-dominant shoulders of overhead athletes. Therefore, the objective of this study is to compare the AHD and change of the AHD during abduction by real-time ultrasonographic measurements between the dominant and non-dominant shoulders of female overhead athletes and to compare between elite and recreational female athletes.

METHODS

Subjects

Sixty-two overhead athletes participated in this study. Twenty-nine female elite handball players who were competing in the highest division of the Dutch Handball League and 33 female recreational overhead athletes of four different sports disciplines (volleyball, water polo, squash and badminton) were included. Athletes with shoulder or elbow pain within 6 months prior to testing were excluded. Other exclusion criteria were neck complaints, traumatic injury at the upper limb and previous shoulder surgery. Both dominant and non-dominant shoulders were tested. Only female athletes were recruited to control for gender differences.[24]

Testing Procedure

Each athlete filled in a questionnaire to check exclusion criteria and register demographic data (age, weight and height) and sports specific information (sports discipline, years of experience, hours of exposure/week, dominant arm).

Sonographic images were obtained by a single investigator, specialized in shoulder ultrasonography, using a Colormaster 128 EXT-IZ (Telemed UAB, Vilnius, Lithuania). A 5-10 MHz linear transducer (HL9.0/40/128Z) was used. Subjects' positions were standardized and corrected before the start of ultrasound scanning. They were seated upright without back support, their feet flat on the ground. When scanning the subacromial space at 0° of shoulder abduction, subjects were asked to keep their arms relaxed along their body with the ulnar side of their hand supported on their thighs and the thumbs pointing upwards. When imaging the subacromial space at 45 and 60° of shoulder abduction, subjects had to actively keep their arm in this position with the elbow flexed 90° and the hand in neutral position with the thumb pointing upwards. To assure that the exact amount of abduction was maintained during measurements, a belt, fixed to the chair and hanging around the subjects' lower arms, was adjusted to this position and subjects were asked to keep this belt just straight, without pulling at it.[25] (Figure 1) This was visually controlled by inspecting the amount of pressure of the belt onto the soft tissues of the lower arm. The amount of abduction was verified with an Acumar™ digital inclinometer (model ACU360, Lafayette Instrument Co.; Lafayette, Indiana). The transducer was positioned in the coronal plane, parallel with the long axis of the humerus, at the location at which the acromiohumeral distance was least.[15,25] Scanning started at random on the dominant or non-dominant side. To investigate test-retest reliability, the group of recreational athletes was reassessed after 6 weeks. Images were saved on the US unit for later AHD measurements.

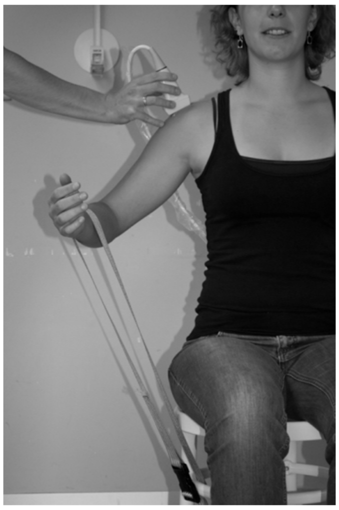

Figure 1. Subject position and probe placement during ultrasonographic AHD measures.

Echowave II Software was used for measuring distances after all images were obtained. AHD was defined as the tangential distance from the most lateral part of the acromion to the humeral head. (Figure 2) Images were labeled as being left or right side of the athlete. The examiner was unaware if the subject was left or right handed when measuring the distances.

Figure 2. Measurement of the AHD on ultrasound image.

Percentage of narrowing during abduction was calculated by subtracting the acromiohumeral distance at the highest abduction degree from the distance at the lower degree and normalizing over the acromiohumeral distance at the lowest ((AHD at 45°- AHD at 0°)/AHD at 0°; (AHD at 60°- AHD at 45°)/AHD at 45°; (AHD at 60°- AHD at 0°)/AHD at 0°). Like this, the percentage of decrease of the acromiohumeral distance is expressed in function of the original size and inter-individual comparison is allowed.

Statistical Analysis

SPSS 19 (SPSS Inc., Chicago, Illinois) was used for statistical analysis. All p-values were two-tailed and considered significant when <0.05. The Shapiro-Wilk test showed normal distribution of the data.

Demographic and sports characteristics were compared between groups with independent samples t-test.

Test-retest reliability analysis included intraclass correlation coefficient ($ICC_{1,k}$) calculation and comparing means with paired samples t-tests. Standard error of measurement (SEM) was calculated with the formula *pooled SD*√(1-ICC)*.

Repeated measures analysis was performed on the AHD measures with "side" (2 levels: dominant, non-dominant) and "degree of abduction" (3 levels: 0°, 45° and 60°) as within-subjects factors and "group" (2 levels: elite athletes, recreational athletes) as between-subjects factor. Post-hoc analysis was done by the software with Bonferroni correction for multiple comparisons. The same analysis was done with the percentages of reduction of the AHD between 0 and 45°, 45 and 60° and 0 and 60°.

ETHICAL CONSIDERATIONS

The study was approved by the Ethical Committee of the Ghent University Hospital and is part of a study registered at Clinicaltrials.gov (NCT01266278). All subjects voluntarily participated and signed an informed consent.

RESULTS

Subject Characteristics

Demographic and sports related characteristics are displayed in Table 1. Statistical analysis showed no significant difference between groups for weight, height and years of experience. Groups were different for age and weekly hours of sports activity. The elite athlete group was younger (Mean difference= 3.9 ±0.6 years) and played significantly more hours a week (Mean difference= 11.0 ±0.8 hours/week).

Table 2. Demographic and sports related characteristics of the overhead athletes.

	Handball Elite (N=29)		Recreational Athletes (N=33)	
	Mean	*SD*	*Mean*	*SD*
Age (years)*	17.9	1.5	21.8	2.6
Height (cm)	173.7	5.8	170.8	5.6
Weight (kg)	69.7	6.1	66.3	7.1
Experience (years)	11.6	2.3	10.1	3.6
Sports activity (hours/ week)*	17.0	3.3	6.0	2.9

*Significant differences between groups were found for age and sports activity

Test-retest reliability of ultrasonographic AHD measures

ICC was 0.92 for AHD measures at 0°, 0.88 at 45° and 0.91 at 60° of shoulder abduction. Means were not significantly different between the two time points. Differences between measures were very small: 0.03 ±1.1mm, 0.07 ±1.16mm and 0.05 ±1.2mm for the AHD measures at 0, 45 and 60° respectively. SEM was equal to 0.54mm at 0° of abduction, 0,87mm at 45° of abduction and 0.75mm at 60° of abduction.

AHD measures

"Side" ($p<0.001$; $F=26.51$) and "group" ($p=0.032$; $F=4.29$) showed significant influence on the AHD (Table 2).

Table 3. Mean acromiohumeral distance (AHD) measurements (mm) at 0°, 45° and 60° of abduction and absolute reduction of AHD from 0° to 45° and from 45° to 60° of abduction. (D= dominant; ND= non-dominant; Abd= abduction; SD= standard deviation; 95%CI= 95% confidence interval)

	Handball Elite				Recreational Athletes			
	D		*ND*		*D*		*ND*	
Abd	*Mean (SD)*	*95%CI*	*Mean (SD)*	*95%CI*	*Mean (SD)*	*95%CI*	*Mean (SD)*	*95%CI*
0°	12.5 (2.1)	11.9 - 13.1	11.3 (1.7)	10.7 - 12.0	11.7 (1.6)	11.1 - 12.3	11.2 (1.7)	10.6 - 11.8
45°	11.3 (2.8)	10.4 - 12.2	10.2 (2.1)	9.5 - 10.9	9.7 (1.9)	8.9 - 10.6	9.0 (1.6)	8.4 - 9.7
60°	10.5 (3.0)	9.6 - 11.4	9.1 (2.3)	8.3 - 9.6	9.3 (1.8)	8.5 - 10.1	8.4 (2.1)	7.7 - 9.2
0-45°	1.2 (2.4)	-	1.1 (1.7)	-	1.8 (1.7)	-	2.2 (1.8)	-
45-60°	0.8 (1.7)	-	1.1 (1.8)	-	0.4 (1.3)	-	0.6 (1.7)	-

For both groups the AHD was found to be larger in the dominant side compared to the non-dominant side at all degrees of abduction (Mean difference= 0.94 ±0.18mm; 95%CI 0.57 - 1.30). Second, it was shown that the AHD was larger in elite handball athletes compared to recreational athletes, independent of side and at all degrees of abduction (Mean difference= 0.92 ±0.47mm; 95%CI 0.08 - 1.75).

Reduction of the AHD during abduction

In both groups "degree of abduction" had a significant influence on the AHD ($p<0.001$; $F=92.94$).(Figure 3)

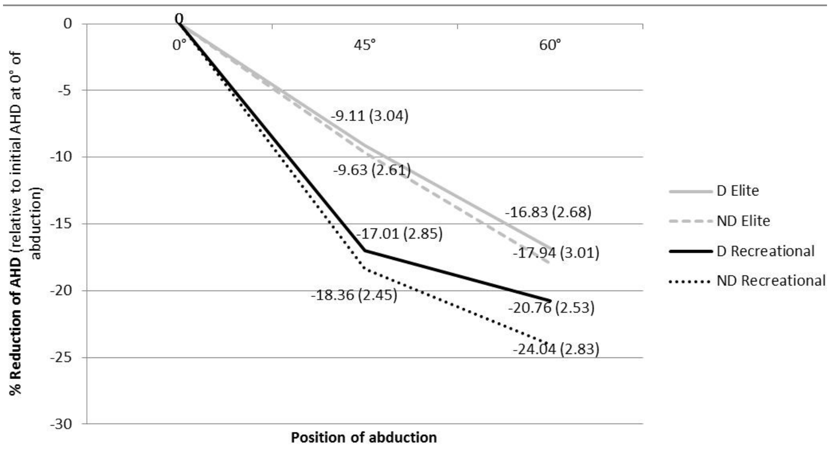

Figure 3. Reduction of acromiohumeral distance from 0° to 45°, and 0° to 60° of abduction (% relative to initial size at 0° of abduction; Mean (SD))

Post hoc tests showed that the AHD significantly reduces from 0 to 45° abduction ($p<0.001$; Mean difference=1.64 ±0.19mm; 95%CI 1.17-2.10) and from 45 to 60° of abduction ($p<0.001$; Mean difference= 0.73 ±0.14mm; 95%CI 0.37-1.08).
In both groups there was no significantly different amount of reduction of the AHD between the dominant (12.25% ±1.26) and non-dominant side (14.65% ±1.54) ($p=0.137$; $F=2.27$). (Figure 3)

Percentage reduction of the AHD during abduction differed significantly between groups at the range of 0-45° of abduction ($p=0.01$; $F= 4.81$). (Figure 3) When moving the arm from 0 to 45° of abduction, the AHD diminishes 9.37% ±2.17 in the elite athletes compared to 17.68% ±2.03 in the recreational athletes. There was no significant difference between both groups in the range from 45 to 60°.

DISCUSSION

The purpose of this study was first to identify the AHD and reduction of AHD during abduction comparing dominant with non-dominant shoulders of female overhead athletes and to compare between elite and recreational female athletes.
This study demonstrated that in both groups the AHD on the dominant side was 0.94±0.18mm larger than that on the non-dominant side in all test positions. When comparing elite and recreational athletes, the AHD was 0.92±0.47mm larger in elite athletes, who trained significantly more hours than the recreational athletes. Considering SEM is a threshold for detecting a true

change rather than error, the detected differences are higher than the calculated SEM of 0.54, 0.87, and 0.75mm at respectively 0°, 45° and 60° of abduction.

To our knowledge, this is the first study to identify the AHD on the dominant and non-dominant side of elite and recreational athletes. Two previous studies investigated the difference in AHD measures from ultrasonography-generated images between overhead athletes and non-athletes. Silva et al. found a smaller size in junior tennis players (8.79±1.52mm) compared to controls (9.80±1.40mm).[15] It should be noted that the tennis players were younger (mean age 14 years) than our population and that 43.4% of the tennis players and 20% of the control group presented with scapular dyskinesia, defined as visual observation of static or dynamic winging of the scapula. Silva et al. found a smaller AHD in subjects with dyskinesis when the arm moves from 0° to 60° but no information is provided on the actual AHD at 0° of abduction in these subjects. Wang et al. compared the AHD of 12 uninjured male baseball players with 16 controls and found contrary to Silva et al. that AHD was significantly larger in the athletes (8.8±3.5mm vs. 5.6±1.5mm).[26] Comparing the mean AHD values of Silva et al. and Wang et al. with ours is not appropriate since their choice of reference points to measure the AHD differed slightly from ours, which resulted in overall lower mean values. In both studies no information is provided on the difference of AHD between dominant and non-dominant side in the athletes. However in the study of Wang et al. mean values are presented in the tables of the uninjured athletes' dominant (8.8±3.5mm) and non-dominant side (7.9±2.5mm) which show the same differences as found in our study. No reports were found on statistical analysis of this difference. Because of these conflicting results of Silva et al. and Wang et al., no conclusions can be drawn on the AHD in athletes compared to non-athletes. Small sample sizes and the lack of a consistent standardized method to measure AHD might be important reasons for the varying results. The lack of a control group with non-athletes is a limitation of our study.

In line with other studies, this study showed that the AHD significantly reduces when the arm moves from 0 to 45 and to 60° of abduction.[15,25] This narrowing occurs to the same amount on the dominant (12.25% ±1.26) and non-dominant side (14.65% ±1.54) of the athletes, relative to the initial size in neutral abduction. When we compare elite with recreational athletes results show significantly less narrowing during the first 45° of abduction in elite athletes (9.37% ±2.17) compared to recreational athletes (17.68% ±2.03). The absolute difference in reduction between groups is small at the dominant side (0.6mm) and larger at the non-dominant side (1.0mm). Clinical relevance of this finding still needs to be determined.

The relationship of a larger AHD and less narrowing during abduction to the risk of developing impingement symptoms is unknown. Patients with rotator cuff disease have shown smaller AHD measures compared to healthy controls from ultrasonography generated images as well as from MRI and radiographs.[27] Desmeules et al. have described a trend for greater narrowing of the subacromial space in patients with rotator cuff tendinopathy compared to healthy controls when moving the arm to 45° of abduction.[28] This is also consistent with results from previous studies using MRI to measure AHD.[29,30] This suggests that the results found in this study are in favor of the dominant side of the overhead athletes and in favor of the elite handball players.
In the present study, healthy athletes were examined so results may not be applied to athletes with shoulder pain. Prospective research is needed to determine if a larger AHD and less narrowing is related to a decreased risk for impingement.
Caution should be taken when applying results to other genders or sports disciplines. Groups were matched for gender as it was shown that gender is related to the size of the AHD. Graichen et al. have shown that females have a smaller subacromial space than males.[24] This limits extrapolation of the results to a male population of overhead athletes. The different sports disciplines of both groups should be mentioned as a limitation of the study. This could have influenced the difference between groups.
Furthermore, it should be noted that measures of AHD captured with ultrasound are 2D linear measures that do not take into account what may occur at other aspects or volume of the subacromial space. Sonographic AHD measures were shown to be sensitive to a change of posture and muscle activity. Kalra et al. have suggested for example that sitting in a more upright posture increases the AHD.[31] Hinterwimmer et al. showed that adducting muscle activity also increases subacromial space width.[32] We accounted for these possible influences as much as possible by strict standardization of the subject's posture and shoulder position.

Recent evidence suggests that there are other causes for rotator cuff tendinopathy besides impingement. Next to extrinsic subacromial impingement, there might be an even more important role for intrinsic degeneration.[2,33] According to this theory, it is not external friction onto the tendon causing rotator cuff tendinopathy, but rather pathology initiating from inside the tendon. Factors causing this degeneration can be for example overuse[34], genetic factors[35] or reduced vascularization[36]. Further investigations are necessary to determine the role of both extrinsic and intrinsic factors in overhead athletes with rotator cuff pathology.
First of all, it would be interesting to repeat the same protocol but use other measurement instruments so that the AHD of the overhead athletes can be measured at higher degrees of abduction. Due to technical reasons this was not possible using ultrasound.

Second, the influence of muscle fatigue after training or after a match should not be underestimated. It has been shown that after fatigue, scapular position changes to a more protracted and anteriorly tilted position and the head of the humerus translates more superiorly.[37-40] Therefore, the influence of shoulder fatigue induced by overhead throwing on the AHD is of interest.

Third, it is necessary to further elucidate the correlation between sports adaptations at the shoulder and the AHD. Our investigation solely focused on the AHD without providing information on the presence of adaptations in the athletes. Silva et al. investigated the correlation between scapular dyskinesis and the AHD in tennis players and found more narrowing in subjects with scapular dyskinesis.[15] It is clinically relevant to investigate the direct correlation between other adaptations, like GIRD and multidirectional instability, and the AHD in healthy overhead athletes. Moreover, genetic factors might also be an important determinant of subacromial space configuration.

We can conclude that the results of this study show a larger AHD on the dominant side of female overhead athletes in three different abduction positions. Comparing elite with recreational athletes shows that the AHD is even larger and less narrowing occurs during the first degrees of abduction in the elite athletes.

Reference List

1 Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. Br J Sports Med. 2010; 44:319-327.
2 Seitz AL, McClure PW, Finucane S, et al. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? Clinical Biomechanics. 2011; 26:1-12.
3 Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. Sports Med. 2008; 38:17-36.
4 Donatelli R, Ellenbecker TS, Ekedahl SR, et al. Assessment of shoulder strength in professional baseball pitchers. J Orthop Sports Phys Ther. 2000; 30:544-551.
5 Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. Am J Sports Med. 2002; 30:20-26.
6 Reagan KM, Meister K, Horodyski MB, et al. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. Am J Sports Med. 2002; 30:354-360.
7 Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. Arthroscopy. 2003; 19:404-420.
8 Lin JJ, Lim HK, Yang JL. Effect of shoulder tightness on glenohumeral translation, scapular kinematics, and scapulohumeral rhythm in subjects with stiff shoulders. J Orthop Res. 2006; 24:1044-1051.
9 Borich MR, Bright JM, Lorello DJ, et al. Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. J Orthop Sports Phys Ther. 2006; 36:926-934.
10 Laudner KG, Moline MT, Meister K. The relationship between forward scapular posture and posterior shoulder tightness among baseball players. Am J Sports Med. 2010; 38:2106-2112.
11 Harryman DT, Sidles JA, Clark JM, et al. Translation of the humeral head on the glenoid with passive glenohumeral motion. J Bone Joint Surg Am. 1990; 72:1334-1343.
12 Muraki T, Yamamoto N, Zhao KD, et al. Effect of posteroinferior capsule tightness on contact pressure and area beneath the coracoacromial arch during pitching motion. Am J Sports Med. 2010; 38:600-607.
13 Forthomme B, Crielaard JM, Croisier JL. Scapular positioning in athlete's shoulder: particularities, clinical measurements and implications. Sports Med. 2008; 38:369-386.
14 Oyama S, Myers JB, Wassinger CA, et al. Asymmetric resting scapular posture in healthy overhead athletes. J Athl Train. 2008; 43:565-570.
15 Silva RT, Hartmann LG, Laurino CF, et al. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. Br J Sports Med. 2010; 44:407-410.
16 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.
17 Myers JB, Laudner KG, Pasquale MR, et al. Scapular position and orientation in throwing athletes. Am J Sports Med. 2005; 33:263-271.
18 Cools AM, Johansson FR, Cambier DC, et al. Descriptive profile of scapulothoracic position, strength and flexibility variables in adolescent elite tennis players. Br J Sports Med. 2010; 44:678-684.
19 Kibler WB. The role of the scapula in athletic shoulder function. Am J Sports Med. 1998; 26:325-337.
20 Page P. Shoulder muscle imbalance and subacromial impingement syndrome in overhead athletes. Int J Sports Phys Ther. 2011; 6:51-58.
21 Baltaci G, Tunay VB. Isokinetic performance at diagonal pattern and shoulder mobility in elite overhead athletes. Scand J Med Sci Sports. 2004; 14:231-238.

22 van Cingel R, Kleinrensink G, Stoeckart R, et al. Strength values of shoulder internal and external rotators in elite volleyball players. J Sport Rehabil. 2006; 15:237-245.
23 van Cingel R, Kleinrensink G, Mulder P, et al. Isokinetic strength values, conventional ratio and dynamic control ratio of shoulder rotator muscles in elite badminton players. Isokinet Exerc Sci. 2007; 15:287-293.
24 Graichen H, Bonel H, Stammberger T, et al. Sex-specific differences of subacromial space width during abduction, with and without muscular activity, and correlation with anthropometric variables. J Shoulder Elbow Surg. 2001; 10:129-135.
25 Desmeules F, Minville L, Riederer B, et al. Acromio-humeral distance variation measured by ultrasonography and its association with the outcome of rehabilitation for shoulder impingement syndrome. Clin J Sport Med. 2004; 14:197-205.
26 Wang HK, Lin JJ, Pan SL, et al. Sonographic evaluations in elite college baseball athletes. Scand J Med Sci Sports. 2005; 15:29-35.
27 Seitz AL, Michener LA. Ultrasonographic measures of subacromial space in patients with rotator cuff disease: a systematic review. J Clin Ultrasound. 2011; 39:146-154.
28 Desmeules F, Minville L, Riederer B, et al. Acromio-humeral distance variation measured by ultrasonography and its association with the outcome of rehabilitation for shoulder impingement syndrome. Clin J Sport Med. 2004; 14:197-205.
29 Hebert LJ, Moffet H, Dufour M, et al. Acromiohumeral distance in a seated position in persons with impingement syndrome. J Magn Reson Imaging. 2003; 18:72-79.
30 Graichen H, Bonel H, Stammberger T, et al. Three-dimensional analysis of the width of the subacromial space in healthy subjects and patients with impingement syndrome. Am J Roentgenol. 1999; 172:1081-1086.
31 Kalra N, Seitz AL, Boardman ND, III, et al. Effect of posture on acromiohumeral distance with arm elevation in subjects with and without rotator cuff disease using ultrasonography. J Orthop Sports Phys Ther. 2010; 40:633-640.
32 Hinterwimmer S, Von Eisenhart-Rothe R, Siebert M, et al. Influence of adducting and abducting muscle forces on the subacromial space width. Med Sci Sports Exerc. 2003; 35:2055-2059.
33 Soslowsky LJ, Thomopoulos S, Esmail A, et al. Rotator cuff tendinosis in an animal model: role of extrinsic and overuse factors. Ann Biomed Eng. 2002; 30:1057-1063.
34 Olsen SJ, Fleisig GS, Dun S, et al. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. Am J Sports Med. 2006; 34:905-912.
35 Tashjian RZ, Farnham JM, Albright FS, et al. Evidence for an inherited predisposition contributing to the risk for rotator cuff disease. J Bone Joint Surg Am. 2009; 91:1136-1142.
36 Rudzki JR, Adler RS, Warren RF, et al. Contrast-enhanced ultrasound characterization of the vascularity of the rotator cuff tendon: age- and activity-related changes in the intact asymptomatic rotator cuff. J Shoulder Elbow Surg. 2008; 17:96-100.
37 Tsai NT, McClure PW, Karduna AR. Effects of muscle fatigue on 3-dimensional scapular kinematics. Arch Phys Med Rehabil. 2003; 84:1000-1005.
38 Chopp JN, O'Neill JM, Hurley K, et al. Superior humeral head migration occurs after a protocol designed to fatigue the rotator cuff: a radiographic analysis. J Shoulder Elbow Surg. 2010; 19:1137-1144.
39 Teyhen DS, Miller JM, Middag TR, et al. Rotator cuff fatigue and glenohumeral kinematics in participants without shoulder dysfunction. J Athl Train. 2008; 43:352-358.
40 Ebaugh DD, McClure PW, Karduna AR. Scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol. J Orthop Sports Phys Ther. 2006; 36:557-571.

CHAPTER 3| ACROMIOHUMERAL DISTANCE AND THREE-DIMENSIONAL SCAPULAR POSITION CHANGE AFTER OVERHEAD THROWING FATIGUE.

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Chapter 3

ABSTRACT

Context Muscle fatigue due to repetitive overhead throwing is considered an important factor contributing to impingement-related rotator cuff pathology in overhead athletes. There is contradicting evidence on scapular and glenohumeral kinematic changes after fatigue which prohibits conclusions on how the acromiohumeral distance (AHD) is affected by shoulder muscle fatigue.

Objective The purpose of this study was to investigate the impact of a fatigue protocol resembling overhead throwing on the AHD and three-dimensional scapular position in overhead athletes.

Design Case series
Setting Laboratory, institutional

Participants Twenty-nine healthy recreational overhead athletes participated in this study (15 female, 14 male, mean age 22.23± 2.82 years).

Data collection and analysis The athletes were tested before and after a shoulder muscle fatiguing protocol. Acromiohumeral distance was measured using ultrasound and scapular position was determined with an electromagnetic motion tracking system (Polhemus 3Space Fastrak®). Both measurements were performed at three elevation positions (0°, 45° and 60° of abduction). Three factor mixed model was used for data analysis.

Results We found that after fatigue, the acromiohumeral distance was significantly increased when the arm was actively positioned at 45° (Δ0.80mm (±0.24), p=0.002) and 60° (Δ0.58mm (±0.23), p=0.020) of abduction. Scapular position was changed after fatigue to a significantly more posteriorly tilted position at 0, 45 and 60° of abduction (Δ1.98° (±0.41), p<0.001), more upwardly rotated position at 45° (Δ6.10° (±1.30), p<0.001) and 60° (Δ7.20° (±1.65), p<0.001) of abduction and more externally rotated position at 45° (Δ4.97° (±1.13), p<0.001) and 60° (Δ4.61° (±1.90), p=0.001) of abduction.

Conclusions After a fatiguing protocol that was close to overhead throwing movement, changes in AHD and scapular position were found in the shoulders of overhead athletes that correspond with a protective, impingement-sparing situation at lower elevation angles.

Keywords shoulder, subacromial impingement syndrome, prevention, ultrasonography

INTRODUCTION

Overhead sports activities place large-magnitude loads onto the upper extremity through repetition of high velocity overhead motion while continuously alternating between acceleration and deceleration.[1] Not surprisingly, overhead athletes often present with shoulder pathology. Disorders of the rotator cuff are frequently the source of pain.[2,3] Subacromial impingement plays an important role in development of rotator cuff pathology.[4] This occurs when there is inadequate space for clearance of the rotator cuff tendons during elevation.[5] Multiple theories exist on why overhead athletes develop impingement related complaints.[6-8] Fatigue of the shoulder muscles due to repetitive overhead throwing has been postulated to contribute to impingement.[9] Since the shoulder musculature plays such an important role in producing and controlling shoulder motion, impairments of these muscles could alter scapular kinematics and influence subacromial space size.

Up to now there is no consensus in literature as to whether scapular upward rotation increases[10-136] or decreases[14,15] when the shoulder is fatigued. Neither is there a consensus on what happens to external rotation and posterior tilt of the scapula after shoulder fatigue.[10-15] Based on these findings clinicians can only indirectly deduce the impact of shoulder muscle fatigue in overhead athletes on the actual size of the subacromial space. No studies have measured the acromiohumeral distance (AHD) before and after shoulder fatigue. Moreover, a lot of studies have used fatiguing protocols which are not resembling overhead throwing fatigue like external rotation, horizontal abduction or elevation exercises.[10,11,14,16] Therefore, the purpose of our study was to investigate the impact of a fatigue protocol resembling overhead throwing on the AHD in overhead athletes through direct measurement of this space by use of ultrasound. At the same time, changes in three-dimensional scapular position were of interest to look at the relationship between these rotations and AHD.

MATERIALS AND METHODS

Subjects

Twenty-nine healthy overhead athletes participated. They were recruited from recreational sports associations (volleyball, tennis, water polo, squash and badminton). To be included in the study, participants had to be aged between 18 and 30 and perform overhead sports activity for at least 2 hours a week. We excluded participants when they had experienced shoulder pain during the last 6 months for which they consulted a medical doctor. Given the possible influence of glenohumeral internal rotation deficit (GIRD) on scapular and glenohumeral kinematics, we excluded athletes with GIRD (>20° asymmetry with contralateral side[7]).[17,18] The local ethics committee approved the study and all participants signed an informed consent.

Data Collection

Athletes filled in a questionnaire to obtain demographic information (gender, age, weight, height), information on their sports activity (what sport, hours/week and years of experience) and on their history of shoulder pain. Each participant underwent a clinical examination including active movements and impingement tests (Hawkins, Neer and Jobe test).[19] In case one of the tests was painful, the athlete was excluded from the investigation. Internal rotation range of motion was measured with an Acumar™ Digital Inclinometer (model ACU360, Lafayette Instrument Co.; Lafayette, IN) prior to the start of the investigation. During this measurement participants were supine with the shoulder 90° abducted and internally rotated until the coracoid process started moving anteriorly.[20] One investigator checked movement of the coracoid process through palpation and the other investigator measured range of motion.

We performed baseline measurements of the AHD on both shoulders, representing the pre fatigue condition. Baseline measurements of three-dimensional scapular kinematics were performed only at the dominant side. Next, the dominant side was fatigued while the non-dominant side was not. The dominant side was defined as the side which was used for overhead throwing during sports activities. Upon completing the fatigue protocol all measurements were repeated, representing the post fatigue condition. The fatigued shoulder was tested first to limit time to measurements and minimize muscle recovery. For the same reason, the fatiguing protocol was performed adjacent to the measurement device and participants were instructed on quick repositioning into the correct positions.

Sonographic images were obtained by a single investigator, specialized in shoulder ultrasonography, using a Colormaster 128 EXT-IZ (Telemed UAB, Vilnius, Lithuania). A 5-10 MHz linear transducer (HL9.0/40/128Z) was used. Subjects' position was standardized and corrected before the start of ultrasound scanning. They were seated upright without back support, their feet flat on the ground. When scanning the AHD at 0° of shoulder abduction, subjects were asked to keep their arms relaxed along their body with the ulnar side of their hand supported on their thighs and the thumbs pointing upwards. For measurement of the AHD at 45 and 60° of shoulder abduction, subjects had to actively keep their arm in this position with the elbow flexed 90° and the hand in neutral position with the thumb pointing upwards. To assure that the exact amount of abduction was maintained during measurements, a belt, fixed to the chair and hanging around the subjects lower arms, was adjusted to this position and subjects were asked to keep this belt just straight, without pulling at it.[21] (Figure 1) The amount of abduction was verified with an Acumar™ digital inclinometer. The transducer was positioned in the coronal plane, parallel with the long axis of the humerus, at the location at which the acromiohumeral distance was least.[21]

Figure 1. Left: Subject position and probe placement during sonographic measurements of the subacromial space. Right: Measurement of the subacromial space on ultrasound image.

We collected three-dimensional scapular kinematics at 30Hz with the Polhemus 3Space Fastrak® (Colchester, VT). This electromagnetic motion tracking system has been used in several studies investigating shoulder girdle motion.[11-13,22,23] An accuracy of 0.15° root-mean-square (RMS) for orientation and 0.76mm RMS for position have been reported by the manufacturer.[24] It consists of a transmitter which emits the signal, three receivers, and a digitizing stylus which are all connected to an electronic unit. The receivers were attached to the bony landmarks with adhesive tape.(Figure 2)

Figure 2. Receiver locations during three-dimensional scapular position measurements. Upper right: Coordinate axes for the local scapular reference frame (AC: acromioclavicular joint, SP: root of scapular spine, IA: inferior angle of scapula)

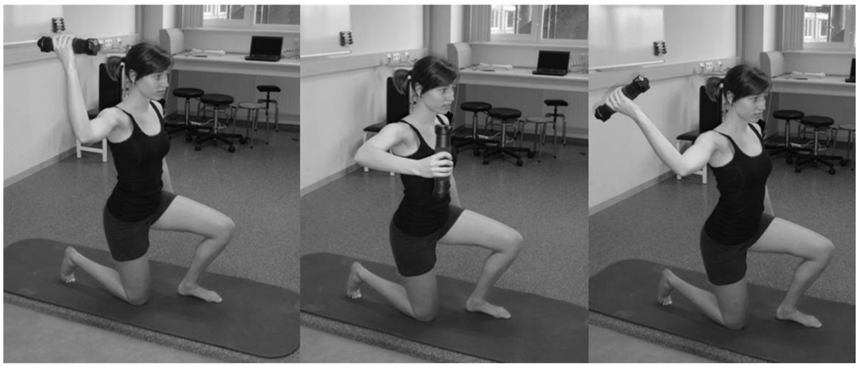
The thoracic receiver was placed on the sternum, just inferior to the sternal notch, the humeral receiver on the upper arm, just distal from the deltoid attachment onto the humerus, and the scapular receiver was placed on the flat surface of the acromion. With the subjects in a seated position, bony landmarks on the thorax, humerus and scapula were palpated and digitized with the stylus.[25] Due to ethical considerations the surface method was preferred over the method with sensors fixed to pins embedded in the bone. Limitations of this surface method were considered and precautions were taken to limit error. The low BMI of our patients exclude potential confounding factors associated with a large amount of soft tissue and abduction positions were limited to much less than 120°, which is considered the limit for reliable motion tracking.[26]

Changes in scapular upward rotation, posterior tilt and external rotation were quantified before and following muscle fatigue. Kinematic data were collected during each of the three static abduction positions of the shoulder (0°, 45° and 60° of abduction) which corresponded with the positions in which ultrasonographic measurements were performed. Each position was held isometrically for 5 seconds and this was repeated three times.

Fatiguing Protocol

To fatigue the dominant shoulder we chose a protocol that was close to the overhead throwing movement on the one hand and easy to standardize on the other hand. The athletes had to move the arm repeatedly from internal to external rotation with the shoulder abducted 90° while holding an XCO-Trainer®.(Figure 3) Resistance of the XCO-Trainer® increased the needed acceleration and deceleration forces similar to an overhead throwing motion. Participants were knelt with the hip of the non-dominant side flexed to 90° and foot flat on the ground. This position was chosen to limit contribution of lower extremity force during the "throwing" motion. No deviation of the upper arm from the frontal plane was allowed. Speed was controlled with a metronome (144 Hz). Fatigue was defined based on both subjective and objective criteria. A Borg Rating of Perceived Exertion (RPE) scale was used to register the athletes subjective experience of fatigue.[27] This scale is a valid measure of local upper extremity exertion.[28] We considered the subjects fatigued when they reported an exertion level exceeding 14 out of 20.[29] A rating of 15 on the Rating of Perceived Exertion scale corresponds with "hard/heavy work or strain and fatigue on muscles".[27] We objectively evaluated correct performance of the movement: no slowing down, no lowering of the upper arm or deviation from the frontal plane and no diminishing of total range of motion were allowed. When quality of movement was considered low the athletes were encouraged to correct performance. The impossibility to do so because of muscle fatigue was used as the objective criteria to quit. The athletes were not aware of criteria used to discontinue the fatigue protocol.

Figure 3. Fatigue protocol.



Data Analysis

We saved all images on the US unit for later acromiohumeral distance measurements. Echowave II Software was used for measuring distances. We defined cromiohumeral distance as the tangential distance from the most lateral part of the acromion to the humeral head. (Figure 1)

Raw kinematic data of the Fastrak were converted to anatomically defined rotations with a custom-made program written in Matlab and displayed with Visual 3D (C-motion, Rockville, MD). The three scapular rotations were defined with an Euler axis sequence (external rotation, upward rotation, and posterior tilting).[25] Means were calculated over the duration of 5 seconds and those data were again averaged over the three trials.

Statistical Analysis

SPSS 19 (SPSS Inc., Chicago, IL) was used for statistical analysis. All p-values were two-tailed and considered significant when <0.05. To determine the influence of fatiguing the dominant shoulder on the AHD in both shoulders a three factor mixed model analysis was used with factors "side" (dominant and non-dominant), "time" (before and after fatigue) and "position" (0°, 45° and 60°). To investigate the influence of dominant shoulder fatigue on scapular kinematics, a two factor mixed model analysis was used with factors "time" and "position". Post-hoc analyses were adjusted with Bonferroni correction.

RESULTS

Gender was evenly distributed (female: male= 15:14). Mean age was 22.23years (±2.82), mean weight 71.6kg (±9.5) and height 178.3cm (±7.8). The mean number of hours of overhead sports activity was 6.5 (3.2) and mean number of years of experience was 9.17 (±3.60).

Results of sonographic acromiohumeral distance measurements on the dominant and non-dominant side and before and after fatiguing the dominant side are presented in table 1 and figure 4.

	Dominant Side			Non-dominant Side		
Abduction Position	Pre Fatigue	Post Fatigue	Post – Pre p-value	Pre Fatigue	Post Fatigue	Post – Pre p-value
0°	11.92 (0.25)	12.15 (0.25)	0.148	11.90 (0.30)	11.93 (0.30)	0.854
45°	10.81 (0.34)	11.61 (0.34)	0.002*	10.24 (0.39)	10.03 (0.39)	0.430
60°	10.21 (0.39)	10.79 (0.39)	0.020*	9.95 (0.36)	10.13 (0.37)	0.527

Table 1. Mean (standard error) sonographic acromiohumeral distance measurements on the dominant and non-dominant side and before and after fatiguing the dominant side (mm). *represents statistical significant difference between pre and post fatigue measurements.

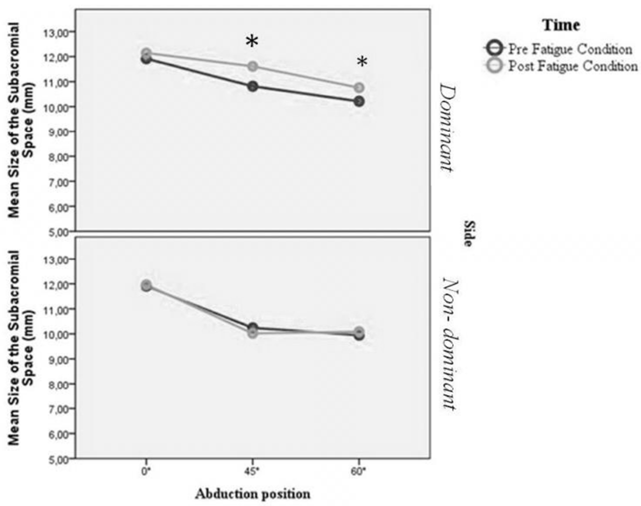
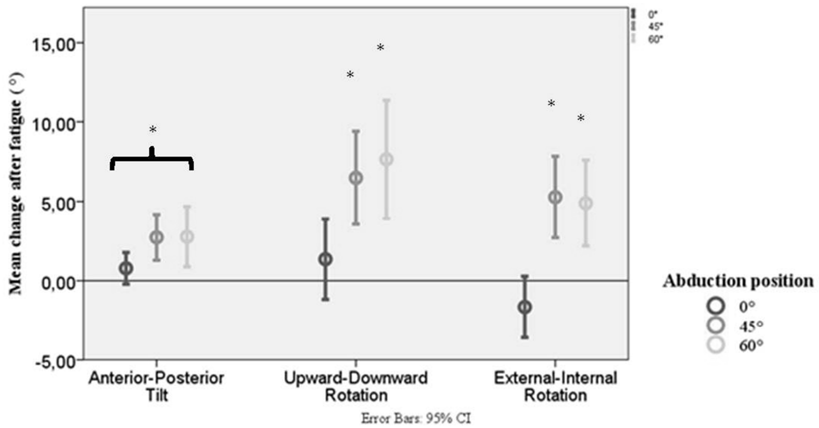


Figure 4. Graphical presentation of sonographic subacromial space measurements on the dominant and non-dominant side and before and after fatiguing the dominant side. X-axis displays the position of abduction at which measurement was performed. Y-axis displays acromiohumeral distance in mm. * indicates statistically significant difference between pre and post fatigue measurements.

Analysis of acromiohumeral distance showed a significant interaction effect of "time x side x position" (p=0.048). Post hoc tests showed that the acromiohumeral distance did not change significantly after fatigue at the position of 0° abduction (Δ= 0.24mm (±0.16), 95% CI [-0.09 – 0,57mm], p= 0.148). On the dominant side the acromiohumeral distance was significantly larger after fatigue at 45° of abduction with a mean increase of 0.80mm (±0.24) (95% CI [0.31 – 1.28mm], p= 0.002) and at 60° of abduction with a mean increase of 0.58mm (±0.23) (95% CI [0.10 – 1.06mm], p= 0.020). Post hoc tests showed no significant change of the acromiohumeral distance at all abduction positions on the non-dominant side, which was not fatigued.

Mean change of the position of the dominant scapula around the three axes before and after fatigue is presented in figure 5.

Figure 5. Graphical representation of the amount of change of scapular position (°) in the three axis after fatigue. Y-axis represents mean change of scapular position after fatigue compared to the prefatigue status. Positive angles represent a more posteriorly tilted, upwardly rotated or externally rotated position of the scapula after fatigue. * indicates a significant change of scapular position.



As to the position of the scapula around the z-axis (anterior-posterior tilt) a significant main effect of "time" was found with an overall change of 1.98° (±0.41) after fatigue (95% CI [1.16 – 2.79°], p<0.001) meaning that after fatigue the scapula was in a more posteriorly tilted position. There was a significant interaction effect of "time x position" for scapular position around the x-axis (upward-downward rotation). Post hoc tests showed that the scapula was in the same position before and after fatigue at 0° of abduction (Δ= 1.35° (±1.07), 95% CI [-0.91 - 3.62°], p=0.223) while in a significantly more upwardly rotated position at 45° (Δ= 6.10° (±1.30), 95% CI

[3.36 – 8.85°], $p<0.001$) and at 60° of abduction (Δ= 7.20° (±1.65), 95% CI [3.72 – 10.69°], $p<0.001$). Comparing the position of the scapula around the y-axis (external-internal rotation) before and after fatigue revealed a significant interaction effect of "time x position" ($p<0.001$). Again there was no significant change of the dominant scapula position at 0° of abduction (Δ= 1.58° (±0.81), 95% CI [-3.30 – 0.13°], $p=0.068$) but at 45° (Δ= 4.97° (±1.13), 95% CI [2.58 – 7.36°], $p<0.001$) and at 60° of abduction (Δ= 4.61° (±1.90), 95% CI [2.10 – 7.12°], $p=0.001$) the scapula was in a significantly more externally rotated position after fatigue.

DISCUSSION

Based on literature it is not clear how muscle fatigue as a result of overhead throwing affects the AHD. With this study we wanted to measure the acromiohumeral distance directly by use of ultrasound before and after a fatiguing protocol with an exercise that resembles overhead throwing. At the same time, we wanted to determine scapular position changes. Like this a change in AHD could be linked to changes of scapular position.

Contrary to what is intuitively believed in clinical practice, we found that after fatigue the acromiohumeral distance significantly increases in the shoulder of healthy overhead athletes when the arm is held actively in a 45 and 60° elevated position. No change is seen in a relaxed position with the arm at 0° of abduction. This coincides with the alterations of three-dimensional scapular position seen after fatigue. The scapula was found to be in a significantly more posteriorly tilted, upwardly and externally rotated position when the arm was 45° and 60° elevated. These positions are believed to result in an increase of the AHD which suggests that the increase in acromiohumeral distance results from the scapular position changes found.[30,31]

This is the first study that directly measured the acromiohumeral distance before and after overhead throwing fatigue. Other studies have investigated the influence of muscle fatigue on three-dimensional scapular position. To put these results in the correct perspective, a distinction must be made based on fatigue protocol type.

Four studies were found that investigated changes of scapular kinematics after a fatiguing repetitive elevation task, also called a global fatigue task.[10,12-147] Ebaugh et al found increased upward rotation and external rotation next to decreased posterior tilt.[12] Mc Quade et al's first study[147] showed less scapular motion while their last study[136] showed more scapular motion after elevation fatigue. Results of their first study however are limited by the very small sample size (n=4). Lastly, Chopp et al also found an increased scapular upward and external rotation and posterior tilt.[100] These results are in general similar to the impingement-sparing changes found in our study after overhead throwing fatigue. It has been suggested that after global shoulder muscle fatigue more compensatory scapular motion is needed to reach the requested angle of elevation and changes of scapular kinematics must be seen as a compensatory strategy.[12]

Next to elevation fatigue, other studies investigated the influence of external rotation fatigue, also called local shoulder fatigue. Two studies found less posterior tilt and external rotation of the scapula after fatigue.[11,15] Upward rotation of the scapula however was shown to increase after external rotation fatigue in the study of Ebaugh et al[11] while decrease in the study of Tsai et al.[15] A third study by Chopp et al showed no significant change of scapular motion after the local fatigue task.[10] The contradictory results of these studies must be seen in light of methodological differences like for example the use of static positions or dynamic elevation for measuring scapular position and criteria used to determine fatigue. Joshi et al was the only fatigue study found on overhead athletes and is best comparable to our study.[9] They performed a prone external rotation fatiguing protocol at 90° of abduction and found more upward rotation afterwards during a diagonal upward movement from horizontal adduction/internal rotation to horizontal abduction/ external rotation. No change was found of posterior tilt and external rotation of the scapula.
Though these results are in line with ours, there is an important difference between the fatigue protocol they used and ours. By using prone external rotation at 90° of abduction only the posterior shoulder muscles were fatigued in the study of Joshi et al.[9] Our fatigue protocol was aimed at fatiguing both muscle groups by high velocity concentric as well as eccentric contractions, similar to the way in which shoulder muscles work during overhead sports activity. No other studies were found that examined three-dimensional scapular position changes after functional fatiguing protocols resembling overhead sports fatigue.

It is presumable that our fatiguing protocol elicited a higher fatigue level of the glenohumeral compared to scapulothoracic muscles. This could explain why our athletes compensated with more scapular motion into an impingement sparing direction. This coincides with the increased AHD found during actively held abduction and suggests that possibly humeral head position on the dominant shoulder of our athletes either didn't change or did not change enough in superior direction to decrease the AHD. Possibly the rotator cuff muscles are not fatigued to a greater extent than the deltoid after the overhead throwing fatigue protocol we used.

The amount of change in scapular position after fatigue, found in our study is small for posterior tilt (overall 1.98° (0.41)), large for external rotation (4.97° (1.13) at 45° of abduction and 4.61° (1.90) at 60° of abduction) and very large for upward rotation (6.10° (1.30) at 45° of abduction and 7.20° (1.65) at 60° of abduction) compared with the above mentioned studies. A difference of more than 3° is generally considered the minimum change to be clinically important.[10-12] The clinical importance of the amount of increase of the acromiohumeral distance (0.78mm (0.24) at 45° and 0.58mm (0.23) at 60° of abduction) after fatigue can be questioned. However, it must be acknowledged that even a small change of the AHD could result in an decreased pressure in the subacromial space. Furthermore, the small standard errors and the absence of almost any change at the non-dominant side (Δ 0.01mm (±0.17)), which was not fatigued, raises credibility of the importance.

Some limitations of this study need to be considered. First of all, AHD measurements were performed at low elevation angles so no information is available on what happens above 60°. The reason for this was the impossibility to display the rotator cuff in the AHD at higher angles using ultrasound.[21] Ultrasound was preferable because of its low cost, safety and ability to investigate the athletes in a seated position, which allows free movement of the scapula. Graichen et al showed that the minimal acromiohumeral distance passes right through the supraspinatus tendon at 30° and 60° of abduction in contrast to the minimal distance at 90° of abduction that is located laterally to the suspraspinatus.[32] This supports the relevance of lower elevations angles in view of rotator cuff tendinopathy.

Second, though resembling an overhead throwing motion, the fatiguing protocol used still differs from overhead throwing on the field. Important differences are the kneeled position we used to limit contribution of the lower limbs and the lack of a horizontal abduction – adduction motion. Since adding these factors would make it "easier" for the shoulder muscles it seems unlikely that this would dramatically alter results. Moreover our subjects spontaneously mentioned after the fatiguing protocol that the experience of muscle fatigue resembled the feeling after a heavy training or game.

Third, it is important to mention that our findings represent changes that occurred immediately after the shoulder muscles were fatigued. Whether or not these patterns change with repeated bouts of muscle fatigue, or how long these changes persist are not known at this time and are areas for future research.

The results of this study necessitate further research on the role of impingement in development of rotator cuff pathology in overhead athletes, since the results suggest that it is possible that overhead throwing fatigue does not narrow the AHD but instead enlarges it. Future studies should use other measurement tools to build upon our results with data at higher elevation angles and other arm positions. Moreover, the correlation between sports adaptations at the shoulder and the AHD needs to be elucidated. Silva et al investigated the correlation between scapular dyskinesis and the AHD in tennis players and found more narrowing in subjects with scapular dyskinesis.[33] Rotator cuff or scapular muscle imbalance[34,35] could also be a contributing factor to impingement, as is GIRD.[17,18,36]

CONCLUSIONS

Muscle fatigue due to repetitive overhead throwing is considered an important factor contributing to impingement-related rotator cuff pathology in overhead athletes. The present study investigated the impact of a fatigue protocol resembling overhead throwing on the ultrasonographic acromiohumeral distance and three-dimensional scapular position in overhead athletes. It was shown that after a fatiguing protocol, acromiohumeral distance was significantly increased and the scapula was in a significantly more upwardly and externally rotated and posteriorly tilted position when the arm was actively held at 45° and 60° of abduction. This corresponds with a protective, impingement-sparing situation and could be explained by the fact that the scapula compensates for glenohumeral shoulder muscle fatigue.

Reference List

1 Fleisig GS, Bolt B, Fortenbaugh D et al. Biomechanical comparison of baseball pitching and long-toss: implications for training and rehabilitation. *J Orthop Sports Phys Ther* 2011; **41**(5):296-303.
2 Blevins FT. Rotator cuff pathology in athletes. *Sports Med* 1997; **24**(3):205-20.
3 Wilk KE, Obma P, Simpson CD et al. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther* 2009; **39**(2):38-54.
4 Seitz AL, McClure PW, Finucane S et al. Mechanisms of rotator cuff tendinopathy: Intrinsic, extrinsic, or both? *Clinical Biomechanics* 2011; **26**(1):1-12.
5 Neer CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *J Bone Joint Surg Am* 1972; **54**(1):41-50.
6 Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. *Sports Med* 2008; **38**(1):17-36.
7 Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy* 2003; **19**(4):404-20.
8 Jobe CM, Coen MJ, Screnar P. Evaluation of impingement syndromes in the overhead-throwing athlete. *J Athl Train* 2000; **35**(3):293-9.
9 Joshi M, Thigpen CA, Bunn K et al. Shoulder external rotation fatigue and scapular muscle activation and kinematics in overhead athletes. *J Athl Train* 2011; **46**(4):349-57.
10 Chopp JN, Fischer SL, Dickerson CR. The specificity of fatiguing protocols affects scapular orientation: Implications for subacromial impingement. *Clin Biomech* 2011; **26**(1):40-5.
11 Ebaugh DD, McClure PW, Karduna AR. Scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol. *J Orthop Sports Phys Ther* 2006; **36**(8):557-71.
12 Ebaugh DD, McClure PW, Karduna AR. Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. *J Electromyogr Kinesiol* 2006; **16**(3):224-35.
13 McQuade KJ, Dawson J, Smidt GL. Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. *J Orthop Sports Phys Ther* 1998; **28**(2):74-80.
14 McQuade KJ, Hwa WS, Smidt GL. Effects of local muscle fatigue on three-dimensional scapulohumeral rhythm. *Clin Biomech* 1995; **10**(3):144-8.
15 Tsai NT, McClure PW, Karduna AR. Effects of muscle fatigue on 3-dimensional scapular kinematics. *Arch Phys Med Rehabil* 2003; **84**(7):1000-5.
16 McQuade KJ, Smidt GL. Dynamic scapulohumeral rhythm: the effects of external resistance during elevation of the arm in the scapular plane. *J Orthop Sports Phys Ther* 1998; **27**(2):125-33.
17 Laudner KG, Moline MT, Meister K. The relationship between forward scapular posture and posterior shoulder tightness among baseball players. *Am J Sports Med* 2010; **38**(10):2106-12.
18 Thomas SJ, Swanik KA, Swanik CB et al. Internal rotation deficits affect scapular positioning in baseball players. *Clin Orthop Relat Res* 2010; **468**(6):1551-7.
19 Cools AM, Cambier D, Witvrouw EE. Screening the athlete's shoulder for impingement symptoms: a clinical reasoning algorithm for early detection of shoulder pathology. *Br J Sports Med* 2008; **42**(8):628-35.
20 Awan R, Smith J, Boon AJ. Measuring shoulder internal rotation range of motion: a comparison of 3 techniques. *Arch Phys Med Rehabil* 2002; **83**(9):1229-34.
21 Desmeules F, Minville L, Riederer B et al. Acromio-humeral distance variation measured by ultrasonography and its association with the outcome of rehabilitation for shoulder impingement syndrome. *Clin J Sport Med* 2004; **14**(4):197-205.

22 Lin JJ, Lim HK, Yang JL. Effect of shoulder tightness on glenohumeral translation, scapular kinematics, and scapulohumeral rhythm in subjects with stiff shoulders. *J Orthop Res* 2006; **24**(5):1044-51.
23 Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther* 2000; **80**(3):276-91.
24 **3SPACE FASTRAK. Users Manual, Revision F, Colchester, VT**. 1993.
25 Wu G, van der Helm FC, Veeger HE et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. *J Biomech* 2005; **38**(5):981-92.
26 Karduna AR, McClure PW, Michener LA et al. Dynamic measurements of three-dimensional scapular kinematics: a validation study. *J Biomech Eng* 2001; **123**(2):184-90.
27 Borg G. Borg's perceived exertion and pain scales. *Champaign, IL: Human Kinetics* 1998.
28 Kang J, Chaloupka EC, Mastrangelo MA et al. Regulating exercise intensity using ratings of perceived exertion during arm and leg ergometry. *Eur J Appl Physiol Occup Physiol* 1998; **78**(3):241-6.
29 Tripp BL, Yochem EM, Uhl TL. Functional fatigue and upper extremity sensorimotor system acuity in baseball athletes. *J Athl Train* 2007; **42**(1):90-8.
30 Atalar H, Yilmaz C, Polat O et al. Restricted scapular mobility during arm abduction: implications for impingement syndrome. *Acta Orthop Belg* 2009; **75**(1):19-24.
31 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.
32 Graichen H, Bonel H, Stammberger T et al. Subacromial space width changes during abduction and rotation--a 3-D MR imaging study. *Surg Radiol Anat* 1999; **21**(1):59-64.
33 Silva RT, Hartmann LG, Laurino CF et al. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. *Br J Sports Med* 2010; **44**(6):407-10.
34 Cools AM, Witvrouw EE, Declercq GA et al. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. *Br J Sports Med* 2004; **38**(1):64-8.
35 Page P. Shoulder muscle imbalance and subacromial impingement syndrome in overhead athletes. *Int J Sports Phys Ther* 2011; **6**(1):51-8.
36 Borich MR, Bright JM, Lorello DJ et al. Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. *J Orthop Sports Phys Ther* 2006; **36**(12):926-34.

CHAPTER 4| QUANTIFYING ACROMIOHUMERAL DISTANCE IN OVERHEAD ATHLETES WITH GLENOHUMERAL INTERNAL ROTATION LOSS AND THE INFLUENCE OF A STRETCHING PROGRAM.

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Chapter 4

ABSTRACT

Background Loss of internal rotation range of motion (ROM) at the dominant side is well documented in overhead athletes. This altered motion pattern has been shown to change glenohumeral and scapular kinematics. This could compromise the subacromial space and explain the association between glenohumeral internal rotation deficit (GIRD) and subacromial impingement.

Purpose First, to quantify acromiohumeral distance (AHD) and compare between the dominant and non-dominant side in overhead athletes with GIRD of more than 15°. Second, to investigate the effect of a sleeper stretch program on ROM and AHD.

Study design Controlled laboratory study

Methods ROM was measured with a digital inclinometer and AHD was measured with ultrasound in 62 overhead athletes with GIRD (>15°) at baseline. Differences between sides were analyzed. Athletes were randomly allocated to the stretch- (n=30) or control group (n=32). The stretch group performed a 6 week sleeper stretch program at the dominant side. Change of range of motion and AHD were measured and analyzed in both groups after 6 weeks.

Results The dominant side showed a significant internal rotation deficit (-24.7°±6.3) and horizontal adduction deficit (-11.8°±7.4) and the dominant side AHD was significantly smaller with the arm at neutral (-0.4mm±0.6) and at 45° (-0.5mm±0.8) and 60° (-0.6mm±0.7) active abduction.

After stretching significant increase of internal rotation (+13.5°±0.8), horizontal adduction (+10.6°±0.9) ROM and AHD (+0.5 to +0.6mm) was observed at the dominant side of the stretch group. No significant change of AHD was seen at the non-dominant side of the stretch group and at both sides of the control group.

Conclusion The AHD, a two-dimensional measure for subacromial space, was found to be smaller at the dominant side in athletes with GIRD and was found to increase after a 6 week sleeper stretch program. These findings might provide insight into the relation between GIRD and subacromial impingement but future studies are needed to determine clinical implications.

Key terms overhead athletes, subacromial space, shoulder impingement syndrome, decreased internal rotation

INTRODUCTION

Asymmetric glenohumeral rotational range of motion (ROM) has been well documented in the shoulders of overhead sports players.[5;9;12;14;30;38] Studies have shown a decrease of internal rotation and a concomitant increase of external rotation at 90° of abduction in the throwing shoulder.[5;9;12;14;30;38] Burkhart et al. termed the loss of degrees of glenohumeral internal rotation of the throwing shoulder compared with the non-throwing shoulder as GIRD (glenohumeral internal rotation deficit).[7] Non-pathological GIRD in healthy athletes of several types of sports disciplines was found to be on average 10°±2 compared with the non-throwing shoulder.[6] The pathological threshold for GIRD is believed to be 20°.[7;25] Recently, increased risk of shoulder injury in athletes with GIRD of more than 20° was indeed shown by Wilk et al.[42]

Both bony and soft tissue adaptations have been associated with GIRD. Increased humeral retroversion was shown in habitual throwers.[9;27;30] This bony adaptation is defined as an increase of the angle between the axis of the elbow joint and the axis through the center of the humeral head.[30] Increased retroversion enables the arm to externally rotate to a greater extent and internally rotate to a lesser extent before being constraint by capsuloligamentous restraints.[9;27] Besides humeral retroversion, posterior shoulder tightness, encompassing tightness of the posterior shoulder capsule and muscles, has been proposed as a major contributor to a loss of internal rotation.[7;39;40] Posterior shoulder tightness is quantified through measurement of cross-chest adduction ROM and was shown to correlate with internal rotation ROM in overhead athletes.[17;25;40] It is hypothesized that posterior shoulder tightness is the result of microtrauma and reactive scarring of the soft tissues from high loads onto the posterior shoulder during the deceleration phase of a throwing motion.[6] Reinold et al. have reported decreased internal rotation ROM immediately after throwing and lasting up to 24 hours after throwing.[31] Moreover, Tehranzadeh et al. and Thomas et al. have shown posterior capsule thickening in athletes with GIRD using MRI and ultrasound respectively.[35;36] These findings support the role of posterior shoulder soft tissue tightness in decreasing internal rotation but the cause-effect relationship remains speculative.

A loss of glenohumeral internal rotation and tightness in the posterior shoulder have been associated with altered kinematics of the glenohumeral as well as the scapulothoracic joint. Anterior and superior migration of the humeral head have been reported after surgical tightening of the posterior shoulder in cadavers.[13] On the other hand increased protraction and anterior tilt and decreased upward rotation of the scapula were shown in healthy athletes displaying posterior shoulder tightness.[4;15;37] These changes of glenohumeral and scapulothoracic kinematics could compromise the subacromial space and contribute to subacromial impingement.[1;34] Current literature provides evidence for an association between GIRD and impingement by showing decreased internal rotation and horizontal adduction ROM in subjects with subacromial impingement.[39;41] However, no studies have directly investigated the size of the subacromial space in athletes with glenohumeral internal rotation loss at the throwing shoulder.

Stretching the posterior shoulder to restore internal rotation ROM is suggested in management of subacromial impingement in overhead athletes.[11] Moreover, stretching has been recommended to prevent shoulder injuries and enhance sports performance.[14;20] Good results were shown with the sleeper stretch and the cross-body stretch to decrease the internal rotation loss.[21] It is not clear if stretching also affects glenohumeral and scapular kinematics and therefore if this would alter the size of the subacromial space.

The objective of this study was twofold. First, we wanted to investigate if the size of the subacromial space differed between the dominant side and non-dominant side of overhead athletes with dominant side internal rotation loss. Second, we were interested if a 6 week dominant side sleeper stretch program would change internal rotation and horizontal adduction ROM and alter the size of the subacromial space.

MATERIALS AND METHODS

Subjects

Healthy overhead athletes with dominant side loss of internal rotation were recruited from recreational sports associations (volleyball, tennis, water polo, squash and badminton). To be eligible for the study, participants had to be aged between 18 and 30 and perform overhead sports activity for at least 2 hours a week. The athletes were included when they had 15° or more GIRD.[37] GIRD was defined as a deficit of internal rotation ROM at the dominant compared with the non-dominant side, regardless of total range of motion. The minimal difference of 15° can be considered a significant amount of GIRD as is it larger than the non-pathological GIRD (10°).[6] On the other hand this criterion permitted to recruit healthy athletes as it is smaller than the GIRD considered pathological (20°) which is often associated with shoulder pathology.[7;25] Participants were excluded when they had experienced shoulder pain during the last 6 months for which they consulted a medical doctor and when they had a history of shoulder surgery or documented structural injuries to the shoulder complex. Hundred-fifteen athletes were screened for eligibility, of which 67 athletes met the criteria. Sixty-two of these agreed to participate in the study. The local ethics committee approved the study and all participants signed an informed consent.

Design overview

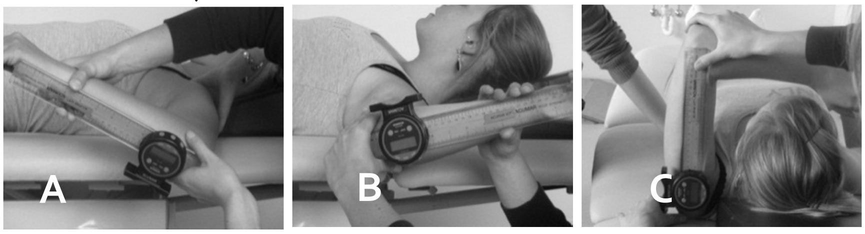
The athletes were randomly allocated to the stretch group (n=30) and the control group (n=32). Block randomization of 4 was used to determine allocation sequence. All measurements were bilaterally performed at baseline and after 6 weeks. The athletes of the stretch group performed the sleeper stretch for 6 weeks at the dominant side. The non-dominant side of the stretch group and both sides of the control group were not stretched. All athletes were tested during September and October 2011 to eliminate a different influence from the athletic season on the change of outcome measurements.

Data Collection

Athletes filled in a *questionnaire* to obtain demographic information (gender, age, weight, height) and information on their sports activity (what sport, hours/week and years of experience). Each participant underwent a clinical examination including active movements and impingement tests (Hawkins, Neer and Jobe test).[8] In case one of the tests was painful, the athlete was excluded from the investigation.

Internal rotation, external rotation and horizontal adduction ROM was measured with an Acumar™ Digital Inclinometer (model ACU360, Lafayette Instrument Co.; Lafayette, IN). All measurements were taken before any exercise, warm-up or throwing activities. Participants were supine. Internal rotation was measured with the shoulder 90° abducted and passively internally rotated until the coracoid process started moving anteriorly.[2] (Figure 1A) One investigator checked movement of the coracoid process through palpation while a second investigator measured ROM.[2] The Acumar™ was mounted on a bar which was aligned from the olecranon to the ulnar styloid process.[26] External rotation was measured with the shoulder 90° abducted and passively externally rotated until end ROM.(Figure 1B) The scapula was fixated by the table and the body weight of the subject. The inclinometer was aligned the same way as for internal rotation measurement. Horizontal adduction was measured with the shoulder at 90° flexion and horizontally adducted until the scapula started moving laterally.(Figure 1C) One investigator manually fixated the lateral border of the scapula and palpated lateral movement of the scapula while the second investigator moved the upper arm towards horizontal adduction and measured the angle between the upper arm and the vertical.[16;19] The inclinometer was aligned with the ventral midline of the humerus. Good reliability of all measurements was repeatedly shown in previous studies.[2;16;19;31] All ROM measurements occurred under supervision of an experienced investigator.

Figure 1. Range of motion measurements (A. Internal rotation, B. External rotation, C. Horizontal adduction)



Sonographic images of the subacromial space were obtained by a single investigator who had 4 years experience with performing research related quantitative shoulder ultrasound. The Colormaster 128 EXT-IZ (Telemed UAB, Vilnius, Lithuania) with a 5-10 MHz linear transducer (HL9.0/40/128Z) was used. Subjects' position was standardized and corrected before the start of ultrasound scanning. They were seated upright without back support, their feet flat on the ground. Two images were obtained at each of the three positions: 0°, 45° and 60° of abduction. When scanning the subacromial space at 0° of shoulder abduction, subjects were asked to keep their arms relaxed along their body with the ulnar side of their hand supported on their thighs and thumbs pointing upwards. For imaging the subacromial space at 45 and 60° of shoulder abduction, subjects had to actively keep their arm in this position with the elbow flexed 90° and the hand in neutral position with the thumb pointing upwards. To assure that the exact amount of abduction was maintained during measurements, a belt, fixed to the chair and hanging around the subjects lower arms, was adjusted to this position and subjects were asked to keep this belt just straight, without pulling at it.[10] (Figure 2) The amount of abduction was verified with an Acumar™ digital inclinometer. The transducer was positioned in the coronal plane, parallel with the long axis of the humerus, at the location at which the acromiohumeral distance (AHD) was least.[10;33] Echowave II Software was used for measuring distances. AHD was defined as the tangential distance from the most lateral part of the acromion to the humeral head.(Figure 2) Mean AHD was calculated for each position from the results of the two measurements. Measurement of the AHD using ultrasound imaging was previously shown to be reliable[10] and valid for quantifying the subacromial space[3].

Figure 2. Left: Subject position and probe placement during ultrasound imaging of the subacromial space. Right: Measurement of the acromiohumeral distance on ultrasound image.

Intervention

The stretch group performed the sleeper stretch at the dominant side daily for 6 weeks (3 repetitions of 30″[16;28]). (Figure 3) A lot of attention was given to correct performance and avoiding compensation. The sleeper stretch was demonstrated and then reproduced by the subjects. The athletes were instructed to perform the stretch in a side lying position on a firm surface with the dominant side below, thorax perpendicular to the ground, head relaxed and supported by a cushion and hips flexed. The dominant upper arm and elbow were both flexed 90°. The non-dominant hand grasped the dorsal side of the dominant wrist and gently pushed into a more internally rotated position until a feeling of stretch but not pain was reached. No pain was allowed at the anterior shoulder region. Attention was drawn to possible compensations which were not allowed:

- decreasing flexion of the dominant upper arm during the stretch
- elevating the scapula of the dominant shoulder
- rolling the non-dominant shoulder posteriorly so that the thorax is no longer perpendicular to the ground

The athletes of the stretch group received a form to take home with an image of sleeper stretch performance, a written summary of the instructions and an overview of compensations to avoid.

Figure 3. Performance of the sleeper stretch

The athletes of the *control group* did not perform the sleeper stretch program and were asked to maintain all other activities at the same level.

Statistical analysis

SPSS 19 (SPSS Inc., Chicago, IL) was used for statistical analysis. All p-values were two-tailed and considered significant when <0.05. Normality of variables was checked with Shapiro-Wilk tests.

Test-retest-reliability was assessed for all outcome measurements using the data of the control group. Intraclass-correlation-coefficients (ICC2,k) and standard errors of measurement (SEM) were calculated.

To investigate the difference in outcome measures between the dominant and non-dominant side, paired samples t-tests were used. To check for differences between the stretch group and the control group at baseline, independent sample t-tests were used. To examine the effect of a 6 week sleeper stretch program, linear mixed model analysis was used with "side" (dominant, non-dominant) and "time" (at baseline and after 6 weeks) as within-subject factors and "group" (stretch group, control group) as between-subject factor. Post-hoc tests were performed with Bonferroni correction.

RESULTS

Demographic data and information on sports activity of the athletes is presented in table 1.

Table 1. Demographics and sports activity information

Variable	**Stretch-group** (n= 30) **(Mean±SD)**	**Control-group** (n=32) **(Mean±SD)**	p-value
Age (Years)	21.4 ±2.5	22.1 ±2.2	0.228
Gender (M:F)	10:20	12:20	
Height (cm)	176.7 ±9.2	175.0 ±8.4	0.454
Weight (kg)	70.0 ±11.2	68.0 ±10.1	0.465
BMI (cm²/kg)	22.3 ±2.4	22.0 ±2.1	0.550
Sports discipline			
• **Volleyball**	24	22	
• **Tennis**	2	4	
• **Handball**	1	2	
• **Badminton**	3	4	
Total hours sports/week	6.8 ±3.2	5.9 ±2.0	0.170
Sports experience (years)	11.2 ±3.9	11.9 ±3.2	0.425

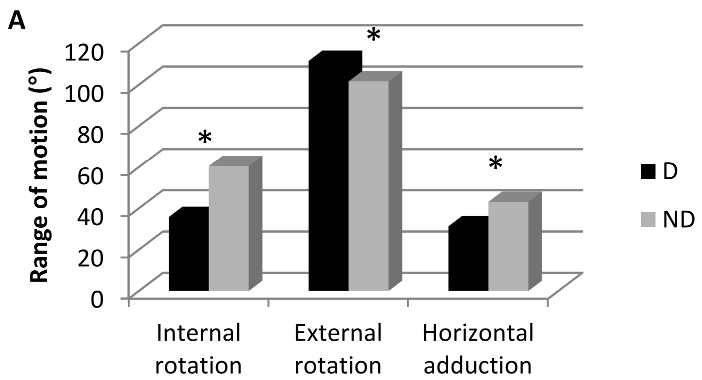
p-values result from independent sample t-tests to compare groups at baseline.

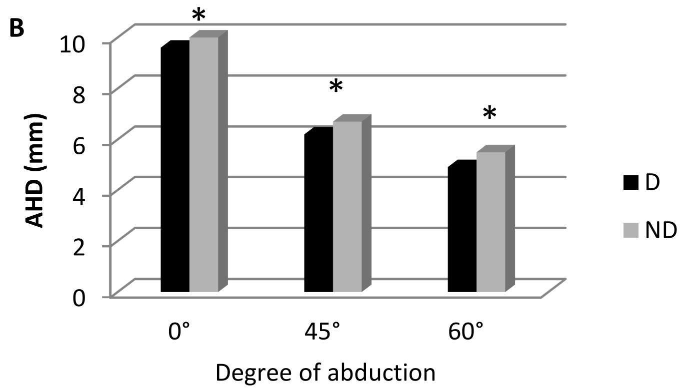
There were no significant differences found between groups at baseline for age, gender, height, weight, BMI, total hours of sports/week and the number of years of sports experience. For internal rotation ROM the ICC was 0.93 and the SEM 1.6°, for external rotation the ICC was 0.80 and the SEM 4° and for horizontal adduction ROM the ICC was 0.91 and the SEM 2.7°. For AHD measures at 0° of abduction the ICC was 0.99 and SEM 0.1mm, at 45° of abduction the ICC was 0.98 and the SEM 0.1mm and at 60° of abduction the ICC was 0.92 and the SEM 0.2mm.

Dominant compared to non-dominant side

Comparison of the outcome measures of the entire study group (containing those in the stretch group and those in the control group) between the dominant and the non-dominant side is presented in figure 4. The dominant side of the athletes showed significantly less internal rotation (MeanΔ=24.7°±6.3) and horizontal adduction (MeanΔ=11.8°±7.4) ROM, significantly more external rotation ROM (MeanΔ=9.9°±8.0, p≤0.001) and a significantly smaller AHD at 0° (MeanΔ=0.4mm±0.6), 45° (MeanΔ=0.5mm±0.8) and 60° (MeanΔ=0.6mm±0.7) (all p≤0.001).

Figure 4. Range of motion (A) and acromiohumeral distance (B) at the dominant and non-dominant side of the 62 athletes with glenohumeral internal rotation loss (Baseline measurements).





D, dominant side; ND, non-dominant side; AHD, acromiohumeral distance

*indicates statistically significant difference between dominant and non-dominant side

Stretch group compared to control group at baseline and after a 6 week stretching program

Mean outcome measures at baseline and after the 6 week stretch program for both shoulders of the stretch and the control group are presented in table 2.

Table 2. Outcome variables (Mean±SD) at baseline (Pre) and after 6 weeks stretching (Post) for the dominant (D) and non-dominant (ND) side of the stretch-group and the control-group.

		Stretch-group				Control-group			
Variable	**Side**	**Pre**	**Post**	**Δ Post – Pre**	**p-value**	**Pre**	**Post**	**Δ Post - Pre**	**p-value**
Internal rotation	D	33.7 ±8.3	47.5 ±7.0	13.5±0.8 [11.8 – 15.2]	**≤0.001***	37.7 ±9.0	39.3 ±8.0	1.7±0.8 [0.0 – 3.4]	0.056
(°)	ND	59.0 ±8.0	58.7 ±8.1	-0.5±0.8 [-2.1 – 1.2]	0.574	61.9 ±9.2	59.5 ±8.8	-2.4±0.7 [-3.7 – -1.0]	**0.001***
External rotation	D	113.7 ±10.5	115.7 ±11.1	1.8±0.7 [0.4 – 3.3]	**0.013**†	109.5 ±8.5	109.8 ±10.7	1.8±0.7 [0.4 – 3.3]	**0.013**†
(°)	ND	103.1 ±10.1	106.5 ±11.2	1.8±0.7 [0.4 – 3.3]	**0.013**†	100.3 ±8.0	102.1 ±8.5	1.8±0.7 [0.4 – 3.3]	**0.013**†
Horizontal add.	D	31.1 ±8.3	42.3 ±8.0	10.6±0.9 [8.8 – 12.5]	**≤0.001***	31.5 ±8.3	32.2 ±7.3	0.6±0.9 [-1.1 – 2.4]	0.456
(°)	ND	44.0 ±10.8	48.8 ±8.9	4.0±1.2 [1.6 – 6.4]	**0.002***	42.3 ±11.7	42.0 ±9.6	-0.3±0.9 [-2.1 – 1.4]	0.727
AHD 0° (mm)	D	9.4 ±1.3	9.9 ±1.2	0.5±0.06 [0.3 – 0.6]	**≤0.001***	9.7 ±1.3	9.6 ±1.2	0.0±0.03 [-0.1 – 0.0]	0.217
	ND	9.8 ±1.6	9.8 ±1.4	0.0±0.04 [-0.1 – 0.1]	0.839	10.1 ±1.4	10.1 ±1.3	0.1±0.04 [-0.1 – 0.0]	0.240
AHD 45° (mm)	D	6.1 ±1.0	6.6 ±0.9	0.5±0.06 [0.4 – 0.7]	**≤0.001***	6.3 ±1.3	6.3 ±1.2	0.0±0.05 [-0.1 – 0.1]	0.976
	ND	6.7 ±1.0	6.6 ±0.9	0.0±0.03 [-0.1 – 0.1]	0.717	6.7 ±1.2	6.7 ±1.1	0.0±0.05 [-0.1 – 0.1]	0.576
AHD 60° (mm)	D	4.9 ±0.9	5.5 ±0.8	0.6±0.08 [0.5 – 0.8]	**≤0.001***	5.0 ±1.0	5.0 ±1.0	0.0±0.03 [0.0 – 0.1]	0.233
	ND	5.5 ±1.1	5.5 ±0.9	0.0±0.06 [-0.1 – 0.1]	0.792	5.5 ±1.1	5.6 ±1.0	0.0±0.04 [0.0 – 1.1]	0.792

Δ Post-Pre represents Mean difference±Standard Error and the 95% confidence interval.

*indicates statistically significant difference Post-Pre (post hoc tests for interaction "side x time x group")

†indicates statistically significant difference Post-Pre (main effect "time")

AHD, acromiohumeral distance; D, dominant; ND, non-dominant

No significant differences were present between groups for the outcome measures (internal and external rotation and horizontal adduction range of motion and AHD at 0°, 45° and 60° abduction) at baseline.

There was a significant interaction effect of "side x time x group" for *internal rotation ROM* (F=21.08, p≤0.001), *horizontal adduction ROM* (F=5.55, p=0.02), *AHD at 0°* (F=8.04, p=0.005), *at 45°* (F=5.93, p=0.016) *and at 60°* (F=9.57, p=0.002).

In the stretch group, internal rotation was significantly increased at the dominant side after 6 weeks of stretching (MeanΔ=13.5°±0.8) (table 2). At the non-dominant side of the stretch group there was no significant change of internal rotation after 6 weeks. Horizontal adduction was significantly increased after 6 weeks at both the dominant (MeanΔ=10.6°±0.9) and non-dominant side (Mean Δ=4.0°±1.2) of the stretch group. AHD was significantly increased at the dominant side of the stretch group at 0° (MeanΔ=0.5mm±0.06), at 45° (MeanΔ=0.5mm±0.06) and at 60° (MeanΔ=0.6mm±0.08). No change of the AHD was found at the non-dominant side of the stretch group after 6 weeks.

In the control group, internal rotation was significantly decreased after 6 weeks at the non-dominant side (MeanΔ=-2.4°±0.7) and unchanged at the dominant side. No change of horizontal adduction nor of the AHD was found after 6 weeks in both sides of the control group.

There was no significant interaction effect of "side x time x group" for external rotation ROM (F=0.00, p=0.990) but a main effect of "time" (F=6.29, p=0.013). After 6 weeks, external rotation was significantly increased in both shoulders of both groups (MeanΔ=1.9°±0.7).(Table 2) This change of external rotation over time was not different between groups nor between sides.

DISCUSSION

Several studies have consistently demonstrated a loss of glenohumeral internal rotation at the dominant side of overhead throwing athletes.[5;9;12;14;30;38] This decreased mobility is empirically linked to posterior shoulder tightness[17;25;40] and to altered glenohumeral and scapulothoracic kinematics.[4;13;15;18;37] Reports on kinematic alterations give us reasons to believe that GIRD could compromise the subacromial space.[1;34] This study therefore investigated the AHD at both shoulders in 62 overhead athletes with a GIRD of more than 15°. The dominant side of all athletes included in the study showed a deficit of internal rotation (-24.7°±6.3) and horizontal adduction (-11.8°±7.4) and a gain of external rotation (+9.9°±8.0) compared with the non-dominant side at baseline. The mean deficit of internal rotation exceeded the pathological threshold of 20° set by Burkhart et al.[7] The AHD at baseline was shown to be significantly smaller at the dominant side at rest (0.4mm ±0.6) and at 45° (0.5mm ±0.8) and 60° (0.6mm ±0.7) active abduction in the overhead athletes with GIRD.

This is the first study to measure AHD in athletes with a loss of glenohumeral internal rotation. Previous studies have quantified the influence of posterior shoulder tightness on subacromial pressure. Muraki et al. showed that tightening the posterior shoulder capsule of cadaveric shoulders increases subacromial contact pressure during shoulder flexion and during the follow-through phase of a throwing motion.[23;24] In contrast, Poitras et al. failed to show a change in subacromial pressure during scapular plane abduction after posterior capsule tightening.[29] The influence of posterior shoulder tightness is likely to depend upon the plane of shoulder motion. Muraki et al. indicated that even a small amount of narrowing of the subacromial space may cause significant changes in contact pressure due to the nonlinear material properties of the soft tissue.[24] Our ultrasonographically measured AHD values are in line with previously reported measures.[10;32;33] No studies could be found on the influence of hand dominance on the AHD. Though differences between sides are small, they could be important as they were larger than the SEM (0.1-0.2mm).

As outlined in the introduction, stretching the posterior capsule to restore internal rotation ROM at the dominant side is recommended. After quantifying the AHD at the shoulders of athletes with GIRD at baseline we were interested if a stretching program could restore internal rotation and horizontal adduction ROM and concomitantly alter AHD. We found internal rotation (+13.5°±0.8) and horizontal adduction (+10.6°±0.9) ROM to be increased at the dominant side of the stretch group after 6 weeks. Surprisingly, the non-dominant side of the stretch group also showed a significant, yet smaller increase of horizontal adduction ROM (+4.0°±1.2) after 6 weeks. A plausible but speculative explanation for this could be an increased awareness of the importance of stretching because of being included in the stretch group. This could have encouraged them to perform all shoulder stretches at training more accurate during these 6 weeks. After 6 weeks, the dominant side of the stretch group also showed a significantly increased AHD at rest (+0.5mm ±0.06) and at 45° (+0.5mm ±0.06) and 60° (+0.6mm ±0.08) active abduction. No significant changes of AHD were found after 6 weeks at the non-dominant side of the stretch group and in the control group. The non-dominant side of the control group instead showed a significantly decreased internal rotation ROM (-2.4°±0.7) after 6 weeks. No explanation could be found for this. Moreover, it was shown that external rotation ROM increased after 6 weeks at both sides of both groups (+1.9°±0.7). As this difference was smaller than the SEM associated with our external rotation measurement (SEM 4°) this change cannot be accepted as clinically significant and is likely due to measurement error.

The results of this study show, in agreement with other studies, that GIRD is reversible and is at least partially attributed to posterior shoulder soft tissue tightness.[14;20] Laudner et al. investigated the acute effects of the sleeper stretch and reported increased internal rotation (+3.1°) and horizontal adduction (+2.3°) ROM. These immediate changes are smaller than the changes found in this study after 6 weeks. McClure et al. found a similar amount of internal rotation ROM increase as in the present study after performing the sleeper stretch for 4 weeks (+12.4°) but an even larger increase after performing the cross-body stretch for 4 weeks (+20°). Future studies should determine if performing the cross-body stretch also brings about an increase of AHD and if it is superior to the sleeper stretch.

This is the first study to show an influence of a 6 week sleeper stretch program on AHD. Though these differences are small, they might relate to a decreased subacromial pressure, both at rest and during active abduction.[24] McClure et al. investigated the effect of posterior shoulder stretching combined with other stretching and strengthening exercises in a group of patients with subacromial impingement.[22] They found that functional improvement of the patients was correlated with the increase of internal rotation range of motion. Future studies are needed to investigate if this finding of McClure et al. in patients with subacromial impingement can be explained by an increased AHD after stretching resulting in decreased subacromial pressure, less pain and better function. The protocol of the present study does not allow to formulate conclusions on the causal relation between GIRD and AHD. Combining our findings of decreased AHD at the dominant side with GIRD and a combined increase of internal rotation ROM and AHD after stretching can only suggest there is an association. The number of subjects included in this study was not sufficient to calculate a correlation between GIRD and AHD. Currently we tested 60 more athletes with GIRD making a total of 122 athletes and in this population we were able to show a significant negative correlation between GIRD and AHD (unpublished data). Wilk et al. have shown a higher prevalence of shoulder injuries in overhead athletes with GIRD.[42] Prospective studies are needed to investigate if a stretching program can reduce this risk.

The following limitations of this study should be mentioned. First, measuring AHD with ultrasound imaging gives a two-dimensional representation of the subacromial space and does not provide information on what happens to other aspects and to the volume of this three-dimensional space. The results of this study do not allow attribution of the increased AHD to an altered position of the humeral head or scapula. Future studies need to examine the influence of a posterior shoulder stretching program on glenohumeral and scapulothoracic kinematics.
Another limitation of our measurement technique is that it is limited to 60° of elevation because of acoustic shadowing at higher angles. As posterior shoulder tightness has been shown to have a more important influence at higher positions of elevation[37] and at end range internal rotation[4], this would be an interesting field for future studies.

Second, it is a limitation that the athletes and the assessors were not blinded for treatment group. This could have introduced measurement bias. In addition, adherence to the stretching program was not monitored in this study. However, the good results strengthen the belief that the sleeper stretch was performed to the best by the athletes in the stretch group.
Lastly, it should be noted that we are not aware of the influence of age and type of sports activity on AHD. Our results cannot be generalized to other age categories. Although possibly subordinate at this recreational level, the heterogeneity of our study group with a majority of volleyball players could have influenced the results. In addition, future studies should include a population of baseball players as they present regularly with substantial range of motion adaptations.

In conclusion, the results of this study showed a smaller AHD at the dominant side of overhead athletes with a GIRD of more than 15°. Performing the sleeper stretch for 6 weeks resulted in an increase of the AHD at the dominant side of the stretch group while the AHD remained unaltered in the control group. Our findings may provide further insight into the relation between GIRD and subacromial impingement.

Reference List

1. Atalar H, Yilmaz C, Polat O, Selek H, Uras I, Yanik B. Restricted scapular mobility during arm abduction: implications for impingement syndrome. *Acta Orthop Belg* 2009;75:19-24.
2. Awan R, Smith J, Boon AJ. Measuring shoulder internal rotation range of motion: a comparison of 3 techniques. *Arch Phys Med Rehabil* 2002;83:1229-1234.
3. Azzoni R, Cabitza P, Parrini M. Sonographic evaluation of subacromial space. *Ultrasonics* 2004;42:683-687.
4. Borich MR, Bright JM, Lorello DJ, Cieminski CJ, Buisman T, Ludewig PM. Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. *J Orthop Sports Phys Ther* 2006;36:926-934.
5. Borsa PA, Dover GC, Wilk KE, Reinold MM. Glenohumeral range of motion and stiffness in professional baseball pitchers. *Med Sci Sports Exerc* 2006;38:21-26.
6. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. *Sports Med* 2008;38:17-36.
7. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy* 2003;19:404-420.
8. Cools AM, Cambier D, Witvrouw EE. Screening the athlete's shoulder for impingement symptoms: a clinical reasoning algorithm for early detection of shoulder pathology. *Br J Sports Med* 2008;42:628-635.
9. Crockett HC, Gross LB, Wilk KE et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med* 2002;30:20-26.
10. Desmeules F, Minville L, Riederer B, Cote CH, Fremont P. Acromio-humeral distance variation measured by ultrasonography and its association with the outcome of rehabilitation for shoulder impingement syndrome. *Clin J Sport Med* 2004;14:197-205.
11. Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. *Br J Sports Med* 2010;44:319-327.
12. Ellenbecker TS, Roetert EP, Bailie DS, Davies GJ, Brown SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Med Sci Sports Exerc* 2002;34:2052-2056.
13. Harryman DT, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA. Translation of the humeral head on the glenoid with passive glenohumeral motion. *J Bone Joint Surg Am* 1990;72:1334-1343.
14. Kibler WB, Chandler TJ. Range of motion in junior tennis players participating in an injury risk modification program. *J Sci Med Sport* 2003;6:51-62.
15. Laudner KG, Moline MT, Meister K. The relationship between forward scapular posture and posterior shoulder tightness among baseball players. *Am J Sports Med* 2010;38:2106-2112.
16. Laudner KG, Sipes RC, Wilson JT. The acute effects of sleeper stretches on shoulder range of motion. *J Athl Train* 2008;43:359-363.
17. Laudner KG, Stanek JM, Meister K. Assessing posterior shoulder contracture: the reliability and validity of measuring glenohumeral joint horizontal adduction. *J Athl Train* 2006;41:375-380.
18. Lin JJ, Lim HK, Yang JL. Effect of shoulder tightness on glenohumeral translation, scapular kinematics, and scapulohumeral rhythm in subjects with stiff shoulders. *J Orthop Res* 2006;24:1044-1051.
19. Lin JJ, Yang JL. Reliability and validity of shoulder tightness measurement in patients with stiff shoulders. *Man Ther* 2006;11:146-152.
20. Lintner D, Mayol M, Uzodinma O, Jones R, Labossiere D. Glenohumeral internal rotation deficits in professional pitchers enrolled in an internal rotation stretching program. *Am J Sports Med* 2007;35:617-621.
21. McClure P, Balaicuis J, Heiland D, Broersma ME, Thorndike CK, Wood A. A randomized controlled comparison of stretching procedures for posterior shoulder tightness. *J Orthop Sports Phys Ther* 2007;37:108-114.

22. McClure PW, Bialker J, Neff N, Williams G, Karduna A. Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program. *Phys Ther* 2004;84:832-848.
23. Muraki T, Yamamoto N, Zhao KD et al. Effect of posteroinferior capsule tightness on contact pressure and area beneath the coracoacromial arch during pitching motion. *Am J Sports Med* 2010;38:600-607.
24. Muraki T, Yamamoto N, Zhao KD et al. Effects of posterior capsule tightness on subacromial contact behavior during shoulder motions. *J Shoulder Elbow Surg* 2011.
25. Myers JB, Oyama S, Wassinger CA et al. Reliability, precision, accuracy, and validity of posterior shoulder tightness assessment in overhead athletes. *Am J Sports Med* 2007;35:1922-1930.
26. Norkin CC, White DJ. *Measurement of Joint Motion: A Guide to Goniometry. 2nd ed*. Philadelphia: Pa:FA Davis, 1995.
27. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med* 2002;30:347-353.
28. Oyama S, Goerger CP, Goerger BM, Lephart SM, Myers JB. Effects of Non-Assisted Posterior Shoulder Stretches on Shoulder Range of Motion Among Collegiate Baseball Pitchers. *Athletic Training and Sports Health Care* 2010;2:163-170.
29. Poitras P, Kingwell SP, Ramadan O, Russell DL, Uhthoff HK, Lapner P. The effect of posterior capsular tightening on peak subacromial contact pressure during simulated active abduction in the scapular plane. *J Shoulder Elbow Surg* 2010;19:406-413.
30. Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk K. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *Am J Sports Med* 2002;30:354-360.
31. 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;36:523-527.
32. Seitz AL, McClure PW, Lynch SS, Ketchum JM, Michener LA. Effects of scapular dyskinesis and scapular assistance test on subacromial space during static arm elevation. *J Shoulder Elbow Surg* 2011.
33. Silva RT, Hartmann LG, Laurino CF, Bilo JP. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. *Br J Sports Med* 2010;44:407-410.
34. 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.
35. Tehranzadeh AD, Fronek J, Resnick D. Posterior capsular fibrosis in professional baseball pitchers: case series of MR arthrographic findings in six patients with glenohumeral internal rotational deficit. *Clin Imaging* 2007;31:343-348.
36. Thomas SJ, Swanik CB, Higginson JS et al. A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. *J Shoulder Elbow Surg* 2011;20:708-716.
37. Thomas SJ, Swanik KA, Swanik CB, Kelly JD. Internal rotation deficits affect scapular positioning in baseball players. *Clin Orthop Relat Res* 2010;468:1551-1557.
38. Torres RR, Gomes JL. Measurement of glenohumeral internal rotation in asymptomatic tennis players and swimmers. *Am J Sports Med* 2009;37:1017-1023.
39. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med* 2000;28:668-673.
40. Tyler TF, Roy T, Nicholas SJ, Gleim GW. Reliability and validity of a new method of measuring posterior shoulder tightness. *J Orthop Sports Phys Ther* 1999;29:262-269.
41. Warner JJ, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *Am J Sports Med* 1990;18:366-375.

42. Wilk KE, Macrina LC, Fleisig GS et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med* 2011;39:329-335.

CHAPTER 5| ELECTROMYOGRAPHIC ANALYSIS OF KNEE PUSH UP PLUS VARIATIONS: WHAT'S THE INFLUENCE OF THE KINETIC CHAIN ON SCAPULAR MUSCLE ACTIVITY?

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Chapter 5

ABSTRACT

Objective First, to look for appropriate closed kinetic chain exercises to restore intramuscular imbalance between upper trapezius (UT) and serratus anterior (SA) in overhead athletes. Second, to determine the influence of using diagonal pattern muscle recruitment during knee push up plus (KPP) exercises on scapular electromyographic activity.

Design Single group repeated-measures design.

Setting Controlled laboratory study.

Participants Thirty-two physically active individuals in good general health who did not have a history of neck and/or shoulder injury or surgery nor participated in highlevel overhead sports or performed upper limb strength training for more than 5 h/week.

Interventions Subjects performed the standard KPP and six variations.

Main outcome measurements Electromyographic activity of the three trapezius parts and the SA.

Results Four exercises with a low UT/SA can be selected for rehabilitation of intramuscular balance: standard KPP, KPP with homolateral leg extension, KPP with a wobble board and homolateral leg extension and one-handed KPP. The use of a wobble board during KPP exercises and performance on one hand has no influence on SA electromyographic activity. Heterolateral leg extension during KPP stimulates lower trapezius activity, whereas homolateral leg extension stimulates SA activity.

Conclusions In case of intramuscular scapular imbalance, some exercises are preferable over others because of their low UT/SA ratio. The use of a kinetic chain approach during KPP exercises influences scapular muscle activity.

INTRODUCTION

Complexity of shoulder biomechanics is expressed in the high prevalence of shoulder injuries in overhead athletes.[1 2] Recently, the role of the scapula in the pathogenesis of shoulder injuries has been given increasing interest.[3–5] Scapular dyskinesis has been associated with subacromial and internal impingement.[6–11] To regain a stable base for the humerus and allow for optimal throwing motion, scapular muscle training is an essential part in rehabilitation of overhead athletes.[4 12 13]

The serratus anterior muscle (SA) is considered to be an important stabiliser of the scapula.[14] Provided cooperation with lower trapezius (LT), SA is optimally positioned to keep the scapula aligned with the thorax and ensure dynamic stabilisation. Weakness of SA is often present in overhead athletes with secondary impingement syndrome.[15–17] Furthermore, intramuscular imbalance between SA and upper trapezius (UT) has been described.[8] The challenge is to find exercises that specifically target the weak SA and minimally activate UT. In a study of Ludewig et al,[18] electromyographic (EMG) activity of SA and UT was measured during the standard push up plus exercise (SPP) and modifications. SPP and knee push up plus (KPP) revealed highest SA activity and lowest UT/SA ratios and are therefore recommended for selective SA strengthening.

Closed kinetic chain exercises have been shown to stimulate mechanoreceptors, which contribute to shoulder joint stabilisation.[4 19–21] This stimulus is suggested to be enlarged by adding an unstable base, possibly resulting in higher EMG activity.[22–24] However, no differences with respect to SA activity were found so far in push-up exercises performed on a mini-trampoline or a Swiss ball.[25–28]
Another push-up modification that possibly increases SA activity is performing the exercise on one hand. An EMG analysis by Uhl et al showed very high activity of the posterior deltoid and infraspinatus during one-handed KPP.[29] However, they did not analyse SA muscle activity.
In overhead athlete rehabilitation, a recent trend is the kinetic chain approach, which tends to incorporate other body segments in shoulder exercises.[30] During a throwing motion, the body works as a dynamic unit and uses lower limbs and trunk to aim for the highest force and velocity at the hand of the throwing arm.[31] Myofascial connections exist, by which lower limb muscle activity might influence scapular muscle activity. When the leg is extended, contraction of the gluteus maximus muscle tightens the thoracolumbar fascia. The stress of the thoracolumbar fascia is transmitted to the heterolateral scapula.[32 33] The influence of leg extension on scapular muscle activity during push-up exercises has not yet been investigated.

The first purpose of this study is to look for appropriate exercises to restore intramuscular imbalance between UT and SA and therefore show high SA activity with low UT/SA ratio. More

specifically, we wanted to investigate the influence of changing three aspects to the KPP on SA EMG activity and UT/SA ratio, namely, the addition of a wobble board, performance on one hand and extension of the homolateral or heterolateral leg.
Second, we wanted to investigate the influence of using diagonal pattern muscle recruitment during KPP exercises on scapular EMG activity of the three trapezius parts and SA.

MATERIALS AND METHODS

Subjects

Thirty-two physiotherapy students (16 men, 16 women) volunteered for this study. They were recruited at the department of Rehabilitation Sciences and Physiotherapy (Ghent University). Mean age was 22.88 years (2.43 years), mean height 1.73 m (0.09 m), mean weight 65.59 kg (8.14 kg), and mean body mass index was 21.95 (±1.84). All participants were physically active, in good general health, without history of neck and/or shoulder injury or surgery. They did not participate in high-level overhead sports nor performed upper limb strength training for more than 5 h/week. All subjects gave informed consent. The Ethical Committee of Ghent University Hospital (Ghent, Belgium) approved the investigation.

Instrumentation

For registration of EMG activity of the three trapezius parts and SA, a Noraxon Myosystem 1400 electromyographic receiver (Noraxon USA, Inc., Scottsdale, Arizona, USA) was used. Sampling rate for data collection was 1000 Hz (bandwidth of 10–1000 Hz). The device had a common mode rejection ratio of 115 dB. Gain was set at 1000 (signal-to-noise ratio <1 µV root mean square (RMS)).
Skin surface was shaved and cleaned to reduce skin impedance (<10 kO). In all participants, the dominant side was tested. Bipolar Ag-Cl surface electrodes (Blue sensor; Medicotest, Ballerup, Denmark) were placed over UT, middle trapezius (MT), LT and SA. SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) recommendations were followed for electrode placement and interelectrode distance.[34] Electrodes for UT were placed halfway between the spinous process of C7 and the posterior acromion. For registration of MT activity, electrodes were placed halfway on the horizontal line between the thoracic spine and the root of the scapular spine. Electrodes for registration of LT activity were placed obliquely upward and laterally along a line between the intersection of the scapular spine with the vertebral border of the scapula and the seventh thoracic spinous process.[12 35–38] Electrodes for SA registration were applied anterior to the latissimus dorsi and posterior to the pectoralis major.[18 26 39] A reference electrode was placed on the sternal part of the homolateral clavicle.
Correct electrode placement was checked and the signal was calibrated.

Testing procedure

In the first part of the investigation, maximal voluntary isometric contractions (MVIC) of UT, MT, LT and SA were quantified for normalisation.[12 38 40] MVIC of UT was measured during resisted isometric abduction. Participants were seated with the arm elevated 90°.[41] To determine MVIC of MT, participants were lying prone with their dominant arm abducted 90° and externally rotated. In this position, resistance was applied to further horizontal abduction. For measurement of MVIC of LT, participants were lying prone with their dominant arm abducted so that the arm was in line with the muscle fibres. Resistance was applied to further horizontal abduction. MVIC of SA was quantified with the participants sitting with their arm flexed forward 130°. Resistance was applied to further elevation. Three repetitions of 5 s were performed with 5 s rest between contractions. This was controlled by a metronome (60 beeps/min). One investigator verbally encouraged the participants. Between MVIC measurements of different muscles, 2 min of rest was provided. This procedure has been used in other EMG studies and has proven useful.[12 18 26]

In the second part of the investigation, participants performed standard KPP (fig 1) and six variations (fig 2). Sequence was randomised to avoid influence of learning or fatigue and prevent order biasing. A metronome was used to control speed of performance (60 beeps/min). Participants completed five repetitions of each exercise with 5 s of rest in between. Between two different exercises, there was a resting period of 2 min.

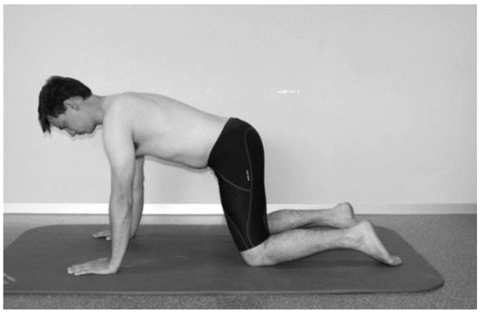

Figure 1. Exercise 1, standard knee push up plus.

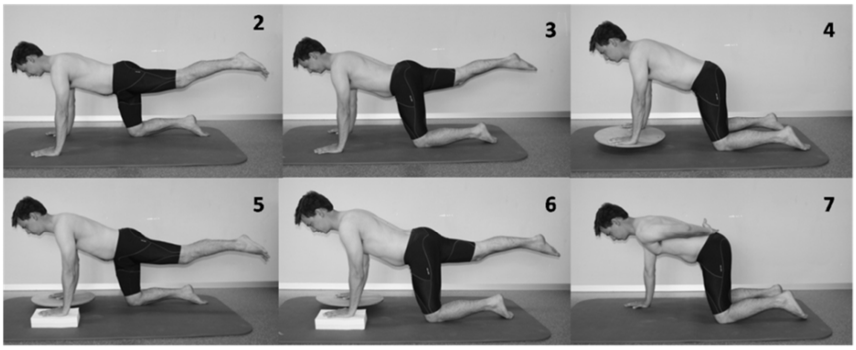

Figure 2. Exercise 2: Knee push up plus (KPP) with heterolateral leg extension. Exercise 3: KPP with homolateral leg extension. Extercise 4: KPP with a wobble board. Exercise 5: KPP with heterolateral leg extension and a wobble board. Exercise 6: KPP with homolateral leg extension and a wobble board. Exercise 7: one handed KPP.

Signal processing and data analysis

Myoresearch 98 Software Program was used for signal processing. Raw EMG signals were converted analog/digital (12-bit resolution) at 1000 Hz. The digital signals were full wave rectified and low-pass filtered (single pass, Butterworth, 6 Hz low-pass filter of the sixth order). Resting EMG activity was considered baseline activity. The three intermediate seconds of every repetition of MVIC were used for further analysis. EMG signals of the first and last repetition of the exercises were not accounted for.

For all subjects, MVIC was averaged across the three intermediate seconds for each muscle. Mean EMG activity of each muscle was calculated across the three intermediate repetitions of every exercise, for all subjects. Those values were subsequently normalised and thus expressed as a percentage of MVIC.

Statistical analysis

SPSS V.15.0 for Windows (SPSS Science, Chicago, Illinois, USA) was used for statistical analysis. Means and SD were calculated across subjects for normalised UT, MT, LT and SA EMG activity of each exercise (table 1).

	UT		MT		LT		SA	
Exercise	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1	13,63	7,27	10,37	5,38	11,30	6,33	31,65	19,11
2	18,31	13,17	14,55	8,28	20,12	10,07	23,43	14,66
3	16,18	8,32	13,04	7,91	11,80	8,14	44,20	18,67
4	13,67	8,00	10,11	5,42	10,44	5,90	25,30	15,77
5	16,69	10,55	13,14	6,00	16,86	9,27	14,27	8,14
6	14,39	7,67	11,44	6,69	10,75	6,68	30,46	15,60
7	17,20	10,52	12,30	6,22	10,72	6,53	36,71	15,55

Table 1. Mean normalized EMG activity of scapular muscles during 7 knee push up plus exercises (% of maximal voluntary isometric contraction). *Exercise 1*: standard knee push up plus (KPP). *Exercise 2*: KPP with heterolateral leg extension. *Exercise 3*: KPP with homolateral leg extension. *Exercise 4*: KPP with a wobble board. *Exercise 5*: KPP with heterolateral leg extension and a wobble board. *Exercise 6:* KPP with homolateral leg extension and a wobble board. *Exercise 7*: one handed KPP.

Ratios were calculated by dividing normalised EMG activity of UT by normalised EMG activity of SA for UT/SA ratio. Means and SD for UT/SA ratio were calculated (table 2). Ratios higher than 1 are not desirable because this implies UT activity is higher than SA. Ratios lower than 1 suggest lower relative UT activity and therefore indicate an exercise is appropriate for restoring muscular balance.

A Kolmogorov–Smirnov test showed normal distribution of the data. First, we wanted to detect differences in normalised EMG activity of UT, LT, MT and SA between the exercises. An analysis of variance (ANOVA) for repeated measures was performed for each muscle with "exercise" as a within-subjects factor (seven levels).
Second, we were interested in finding differences in UT/SA ratios between the exercises. Therefore, ANOVA for repeated measures was performed with exercise as a within-subjects factor (seven levels). In case of significance of Mauchly's test of sphericity, Greenhouse–Geisser correction was performed. The a level for ANOVA was set at 0.05. Post hoc analysis was done with Bonferroni correction for multiple comparison.

RESULTS

Intramuscular balance UT/SA

UT/SA ratios (table 2) were very advantageous in general. As to mean UT/SA ratios, clinically relevant and statistically significant differences were found ($F=15.119$; $p<0.01$). Exercise 3 shows the lowest UT/SA ratio of all exercises and is significantly different from UT/SA in exercises 1 ($p=0.001$), 2 ($p=0.005$), 5 ($p<0.001$) and 6 ($p<0.001$). Thus, extension of the homolateral leg during KPP lowers the UT/SA ratio. Furthermore, UT/SA ratio in exercise 6 (0.54 (0.30)) is significantly lower than UT/SA in exercise 5 ($p=0.002$). This supports the positive influence on UT/SA ratio of homolateral leg extension. UT/SA ratios in exercise 2 ($p=0.03$) and in exercise 5 ($p=0.002$) were significantly higher than in the first exercise (KPP). Therefore we can conclude extension of the heterolateral leg results in a higher UT/SA ratio.

UT/SA in exercise 2 is significantly lower than UT/SA in exercise 5 ($p=0.017$), and UT/SA in exercise 3 is significantly lower than UT/SA in exercise 6 ($p<0.01$). Apparently, addition of a wobble board results in an increase of UT/SA. Finally, UT/SA ratio in exercise 7 is not significantly different from UT/SA in exercise 1. One-hand support does not change UT/ SA ratio in comparison with standard KPP.

SA EMG activity

Statistical analysis showed significant differences in SA activity (table 1) between the exercises ($F=59.048$; $p<0.001$). When the homolateral leg is extended (exercise 3), SA activity is significantly higher than in all other exercises ($p<0.001$).

SA activity in exercise 2 is significantly lower than in exercises 1 ($p=0.001$), 6 ($p=0.004$) and 7 ($p<0.001$). SA activity in exercise 5 is significantly lower than in all other exercises (all $p<0.001$). Thus, heterolateral leg extension generates a lower mean SA EMG activity.

SA activity in exercise 6 is significantly lower than SA activity in exercise 3 ($p<0.001$), which implies that adding a wobble board lowers SA activity. This phenomenon is also obvious when comparing SA activity in exercise 5 with that in exercise 2 ($p<0.001$) and when comparing SA activity in exercise 4 and exercise 1 ($p<0.001$). There is no significant difference in SA activity between exercises 7 and 1, which indicates performing a KPP on one hand has no influence on SA activity.

UT, MT and LT EMG activity

When considering mean normalised EMG activity of UT, MT and LT (table 1), values are overall very low during KPP and variations. We compared trapezius EMG activity in exercise 2 with that in exercise 1 and trapezius EMG activity in exercise 5 with that in exercise 4 because these

exercises only differ in the extension of the heterolateral leg. To clear out the influence of homolateral leg extension, we compared exercise 3 to 1 and exercise 6 to 4.
LT mean normalised EMG activity shows consistent significant differences ($F=25.795$; $p<0.001$). Both exercises during which the heterolateral leg was extended show a significantly higher LT activity than all other exercises. LT activity in exercise 2 is significantly higher than LT in exercises 1 ($p<0.001$) and LT activity in exercise 5 is significantly higher than LT in exercise 4 ($p<0.001$).
There is no significant difference in LT activity when the homolateral leg is extended. With regard to UT and MT mean normalised EMG activity, significant differences were present, but none of them were useful to answer our research questions. There was no pattern present in the results for EMG activity of the upper two trapezius parts.

DISCUSSION

From a clinical point of view, it is especially of interest which exercises are appropriate for restoration of scapular muscle balance in overhead athletes. Four exercises, showing low UT/SA ratio, can be selected, namely, standard KPP, KPP with homolateral leg extension, KPP on a wobble board with homolateral leg extension and one-handed KPP. KPP with extension of the homolateral leg shows the lowest UT/SA ratio with highest mean SA activity (44.20%). These closed kinetic chain exercises should be used in the early stages of scapular strength training.[42 43] Once a stable scapular base is achieved, shoulder rehabilitation should gradually progress towards functional open chain exercises.

To investigate more specifically the effect of an unstable surface on SA muscle activity, we compared exercises 2 and 5, 3 and 6, and 1 and 4 because the presence of a wobble board is the only difference between them. SA activity decreased by adding a wobble board. This is possibly due to the higher position of the hands, placing more weight on lower and less on upper extremities. Lehman et al found similar results. They showed SA activity increases when more weight is placed on the upper extremities by elevating the feet during SPP.[27] Further research should investigate if eliminating height difference in upper and lower extremity support or adding an unstable base at lower extremity support results in higher SA EMG activity. However, we should be aware of the possibility that the use of an unstable surface influences other aspects of motor control, such as muscle timing or recruitment patterns, rather than muscle activity itself.
To answer the question whether SA muscle activity changes when KPP is performed on one hand, we compared exercises 1 and 7. Our results showed no significant differences, which indicates that SA muscle activity is not influenced by performance on one hand. Other muscles than SA probably provide the additional stabilising muscle activity needed.

The second objective of this study was to identify the influence of leg extension on scapular EMG activity. Many clinicians use the principle of the kinetic chain in athlete shoulder rehabilitation, mostly by extending the heterolateral leg to increase scapular activity in a diagonal pattern, but there has never been any investigation to confirm this approach. To answer this question, we compared scapular muscle activity during exercise 1 and exercises 2 and 5. When extending the heterolateral leg, LT activity increases and SA activity decreases. Myofascial connections, as described by Meyers et al and Porterfield and DeRosa, can provide a possible explanation for these results.[32 33] Extension of the heterolateral leg generates gluteus maximus activity, which tightens the thoracolumbar fascia in the direction of the contralateral scapula. This probably facilitates LT with consequently higher muscle fi bre recruitment. It would be interesting to investigate the role of the latissimus dorsi in this. Possibly, the scapula is destabilised by this muscle when the heterolateral leg is extended and therefore requires higher LT activity.
SA on the other hand has been described as part of an anterior flexion chain that runs from the heterolateral leg flexion musculature and internal oblique muscle, through the homolateral external oblique muscle to SA. When the heterolateral leg is extended, antagonistic leg flexion musculature is inhibited. Consequently, the anterior flexion chain is not operative. This could explain why SA activity is lower when the heterolateral leg is extended.
To clear out the influence of homolateral leg extension, we compared scapular muscle activity during exercise 1 and exercises 3 and 6. Because there were no differences in LT activity, we can conclude homolateral leg extension has no effect on LT muscle fibre recruitment. This is in agreement with the explanation given above. When the homolateral leg is extended, this exerts an effect to the heterolateral scapula along the posterior extension chain but not to the homolateral shoulder. The heterolateral leg bears more weight, resulting in a higher stabilising muscle activity encompassing the hip. This activates heterolateral internal oblique muscle, which in turn stimulates homolateral external oblique muscle activity, possibly resulting in higher SA muscle fibre recruitment.

Extrapolation of these results to other age categories or to shoulder patients should be performed with caution because our study population consisted of young, healthy subjects. Ludewig et al[18] investigated scapular EMG activity during push-up exercises in both healthy subjects and subjects with shoulder dysfunction. They found no differences in how both groups responded across the exercises. However, it is more appropriate to investigate this with the exercises from this study before drawing conclusions. Furthermore, we should note that although our results are a good basis for selection of appropriate exercises for rehabilitation of scapular intramuscular balance, no proof has been given that training results in better scapular function. This is an interesting topic for further investigation.

Another important limitation of this study is the use of surface EMG during dynamic movements. Precautions were taken by following SENIAM prescriptions and by maximal standardisation and accuracy.[34] In addition, we strictly followed recommendations of previous investigations that used surface EMG to analyse scapular muscle activity.[12 18 26 44] However, despite precautions, cross talk could have occurred during measurements.

CONCLUSION

We investigated scapular EMG activity during KPP and six commonly used variations. Four exercises with low UT/SA ratio can be selected for rehabilitation of intramuscular balance in overhead athletes with scapulothoracic dysfunction: standard KPP, KPP with homolateral leg extension, KPP with a wobble board and homolateral leg extension and one-handed KPP. The use of a wobble board during KPP exercises nor the performance of KPP on one hand has an influence on scapular muscle EMG activity. It would be interesting to investigate other aspects of motor control, such as muscle timing and recruitment patterns, during KPP exercises and variations.

When using a kinetic chain approach during KPP, heterolateral leg extension increases LT activity, whereas homolateral leg extension increases SA activity. Further research should investigate EMG activity of the important muscles involved in anterior and posterior muscle chains, such as gluteus maximus, latissimus dorsi and the abdominal muscles, to determine their role in this.

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Reference List

1. Almekinders LC. Impingement syndrome. Clin Sports Med 2001;20:491–504.
2. McMaster WC, Troup J. A survey of interfering shoulder pain in United States competitive swimmers. Am J Sports Med 1993;21:67–70.
3. Forthomme B, Crielaard JM, Croisier JL. Scapular positioning in athlete's shoulder: particularities, clinical measurements and implications. Sports Med 2008;38:369–86.
4. Kibler WB. The role of the scapula in athletic shoulder function. Am J Sports Med 1998;26:325–37.
5. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 2009;39:90–104.
6. Endo K, Ikata T, Katoh S, et al. Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome. J Orthop Sci 2001;6:3–10.
7. Hébert LJ, Moffet H, McFadyen BJ, et al. Scapular behavior in shoulder impingement syndrome. Arch Phys Med Rehabil 2002;83:60–9.
8. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276–91.
9. McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. Phys Ther 2006;86:1075–90.
10. Su KP, Johnson MP, Gracely EJ, et al. Scapular rotation in swimmers with and without impingement syndrome: practice effects. Med Sci Sports Exerc 2004;36:1117–23.
11. Warner JJ, Micheli LJ, Arslanian LE, et al. Scapulothoracic motion in normal shoulders and shoulders with glenohumeral instability and impingement syndrome. A study using Moiré topographic analysis. Clin Orthop Relat Res 1992;191–9.
12. Cools AM, Dewitte V, Lanszweert F, et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? Am J Sports Med 2007;35:1744–51.
13. Meyer KE, Saether EE, Soiney EK, et al. Three-dimensional scapular kinematics during the throwing motion. J Appl Biomech 2008;24:24–34.
14. Smith R Jr, Nyquist-Battie C, Clark M, et al. Anatomical characteristics of the upper serratus anterior: cadaver dissection. J Orthop Sports Phys Ther 2003;33:449–54.
15. Glousman RE. Instability versus impingement syndrome in the throwing athlete. Orthop Clin North Am 1993;24:89–99.
16. Scovazzo ML, Browne A, Pink M, et al. The painful shoulder during freestyle swimming. An electromyographic cinematographic analysis of twelve muscles. Am J Sports Med 1991;19:577–82.
17. Schmitt L, Snyder-Mackler L. Role of scapular stabilizers in etiology and treatment of impingement syndrome. J Orthop Sports Phys Ther 1999;29:31–8.
18. Ludewig PM, Hoff MS, Osowski EE, et al. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. Am J Sports Med 2004;32:484–93.
19. Andrews JR, Dennison JM, Wilk KE. The signifi cance of closed chain kinetics in upper extremity injuries from a physician's perspective. J Sport Rehabil 1996;5:64–70.
20. Kibler WB. Closed kinetic chain rehabilitation for sports injuries. Phys Med Rehabil Clin N Am 2000;11:369–84.
21. Ubinger ME, Prentice WE, Guskiewicz KM. Effect of closed kinetic chain training on neuromuscular control in the upper extremity. J Sport Rehabil 1999;8:184–94.
22. Anderson KG, Behm DG. Maintenance of EMG activity and loss of force output with instability. J Strength Cond Res 2004;18:637–40.
23. Lephart SM, Henry TJ. The physiological basis for open and closed kinetic chain rehabilitation for the upper extremity. J Sport Rehabil 1996;5:71–87.
24. Wilk KE, Arrigo CA, Andrews JR. Closed and open kinetic chain exercise for the upper extremity. J Sport Rehabil 1996;5:88–102.
25. de Oliveira AS, de Morais Carvalho M, de Brum DP. Activation of the shoulder and arm muscles during axial load exercises on a stable base of support and on a medicine ball. J Electromyogr Kinesiol 2008;18:472–9.

26. Lear LJ, Gross MT. An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. J Orthop Sports Phys Ther 1998;28:146–57.
27. Lehman GJ, MacMillan B, MacIntyre I, et al. Shoulder muscle EMG activity during push up variations on and off a Swiss ball. Dyn Med 2006;5:7.
28. Lehman GJ, Gilas D, Patel U. An unstable support surface does not increase scapulothoracic stabilizing muscle activity during push up and push up plus exercises. Man Ther 2008;13:500–6.
29. Uhl TL, Carver TJ, Mattacola CG, et al. Shoulder musculature activation during upper extremity weight-bearing exercise. J Orthop Sports Phys Ther 2003;33:109–17.
30. McMullen J, Uhl TL. A kinetic chain approach for shoulder rehabilitation. J Athl Train 2000;35:329–37.
31. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. Sports Med 2006;36:189–98.
32. Porterfield JA, DeRosa C. Mechanical shoulder disorders. Perspectives in functional anatomy. St Louis, Missouri, USA: Elsevier Science, 2004.
33. Meyers TW. Anatomy trains. Myofascial meridians for manual an movement therapists. Edinburgh: Churchill Livingstone, 2001.
34. Hermens HJ, Freriks B, Disselhorst-Klug C, et al. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000;10:361–74.
35. Cools AM, Witvrouw EE, Declercq GA, et al. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. Br J Sports Med 2004;38:64–8.
36. Cools AM, Witvrouw EE, Mahieu NN, et al. Isokinetic scapular muscle performance in overhead athletes with and without impingement symptoms. J Athl Train 2005;40:104–10.
37. Cools AM, Declercq GA, Cambier DC, et al. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scand J Med Sci Sports 2007;17:25–33.
38. Basmajian JV, De Luca CJ. Muscles alive: their functions revealed by electromyography, 5th edn. Baltimore, Maryland, USA: Williams and Wilkins, 1985.
39. Decker MJ, Hintermeister RA, Faber KJ, et al. Serratus anterior muscle activity during selected rehabilitation exercises. Am J Sports Med 1999;27:784–91.
40. Ben Kibler W, Sciascia A. Rehabilitation of the athlete's shoulder. Clin Sports Med 2008;27:821–31.
41. Schüldt K, Harms-Ringdahl K. Activity levels during isometric test contractions of neck and shoulder muscles. Scand J Rehabil Med 1988;20:117–27.
42. Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. J Am Acad Orthop Surg 2003;11:142–51.
43. Wilk KE, Arrigo C. Current concepts in the rehabilitation of the athletic shoulder. J Orthop Sports Phys Ther 1993;18:365–78.
44. de Araújo RC, Tucci HT, de Andrade R, et al. Reliability of electromyographic amplitude values of the upper limb muscles during closed kinetic chain exercises with stable and unstable surfaces. J Electromyogr Kinesiol 2009;19:685–94.

CHAPTER 6| DOES ADDING HEAVY LOAD ECCENTRIC TRAINING TO REHABILITATION OF PATIENTS WITH UNILATERAL SUBACROMIAL IMPINGEMENT RESULT IN BETTER OUTCOME? A RANDOMIZED, CLINICAL TRIAL.

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Chapter 6

ABSTRACT

Purpose To investigate superior value of adding heavy load eccentric training to conservative treatment in patients with subacromial impingement.

Methods Sixty-one patients with subacromial impingement were included and randomly allocated to the traditional rotator cuff training (TT) group (n=30, mean age=39.4 ±13.1 years) or traditional rotator training combined with heavy load eccentric training (TT+ET) group (n=31, mean age=40.2 ±12.9 years). Isometric strength was measured to abduction at 0°, 45° and 90° of scapular abduction and to internal and external rotation. The SPADI questionnaire was used to measure shoulder pain and function. Patients rated subjective perception of improvement. Outcome was assessed at baseline, at 6 and 12 weeks after start of the intervention. Both groups received 9 physiotherapy treatments over 12 weeks. At home, the TT group performed traditional rotator cuff strengthening exercises 1x/day. The TT+ET group performed the same exercises 1x/day and a heavy load eccentric exercise 2x/day.

Results After treatment, isometric strength had significantly increased in all directions and SPADI-score had significantly decreased. The TT+ET group showed a 15% higher gain in abduction strength at 90° of scapular abduction. Chi-square tests showed patients self-rated perception of improvement was similar in both groups.

Conclusion Adding heavy load eccentric training resulted in a higher gain in isometric strength at 90° of scapular abduction but was not superior for decreasing pain and improving shoulder function. This study showed that the combination of a limited amount of physiotherapy sessions combined with a daily home exercise program is highly effective in patients with impingement.

Level of Evidence 2

Keywords shoulder impingement syndrome, physiotherapy, eccentric training, tendon

INTRODUCTION

In current clinical practice, shoulder patients make up a large part of total patient population [6]. Disorders of the rotator cuff are the most common cause of shoulder pain [37]. When Neer introduced the term "subacromial impingement" in 1972, this referred to mechanical abrasion of the subacromial structures against the anterior undersurface of the acromion and coracoacromial ligament [26]. The supraspinatus tendon is usually the most affected structure due to its position in the subacromial space. Histological examinations of the supraspinatus tendon in patients with impingement syndrome have shown degenerative changes, similar to the changes found in Achilles and patellar tendinosis.[16]

The presence of tendon degeneration in patients with impingement could have important implications for treatment. Possibly physiotherapy should not only focus on decreasing impingement but should additionally address this tendon degeneration. In patella and Achilles tendinopathy, eccentric training has shown to not only decrease pain and improve function but also repair tendon tissue [18,24,28]. The Achilles tendon was shown to respond to eccentric training load with an increased collagen production [18]. As to rotator cuff tendinopathy, three studies have been executed and have shown promising clinical results [4,7,14]. Jonsson et al investigated the effect of an eccentric empty can (thumb down) abduction exercise for the supraspinatus without additional treatment in 9 patients with impingement [14]. Five patients were satisfied with treatment and showed less pain and better function after 12 weeks of training. Bernhardsson et al investigated the effect of eccentric rotator cuff training in 10 subjects with subacromial impingement and showed decreased pain in 8 of 10 subjects and better function in all subjects after 12 weeks [4]. Due to small sample size and the lack of a control group in both studies, conclusions cannot be drawn. Recently, Camargo et al showed good results with an isokinetic eccentric training program in a larger group of patients with impingement (n=20) [7]. Still it remains unclear whether eccentric training would substantially augment results of traditional conservative treatment.

The aim of this study was to examine superior value of adding heavy load eccentric training to conservative rehabilitation with respect to increasing strength and decreasing pain and dysfunction. The hypothesis was first, that both groups would have increased strength and decreased pain and dysfunction after rehabilitation and second, that adding eccentric training would lead to superior results.

MATERIALS AND METHODS

Prior to the intervention, baseline outcome measurements were performed. Subsequently, patients were randomly allocated to the traditional rotator cuff strength training (TT) group or the TT combined with heavy load eccentric training (TT+ET) group. All exercises were performed at home for 12 weeks. Both groups attended one physiotherapy session (30') a week during the first period of 6 weeks and one every two weeks during the last period of 6 weeks (9 sessions in total). Outcome variables were reassessed at 6 and at 12 weeks after the start of the intervention.

Setting and Participants

Sample size was estimated based on variability of pilot data. Isometric strength to abduction at 90° of scapular abduction was chosen to calculate sample size as this test is used for manual muscle testing of the supraspinatus. To detect a difference between groups of 10% with a probability level of α=0.05 and a statistical power of p=0.80, 27 subjects were required in each group. A difference in isometric strength of 10% or more was previously reported to be clinically significant [36]. All subjects were recruited by a specialized shoulder surgeon based on a thorough history and physical examination. The surgeon referred for technical investigation when there was doubt upon the diagnosis. The inclusion criteria were: aged over 18 years, unilateral pain for at least 3 months in the anterolateral region of the shoulder, painful arc, 2 out of 3 impingement tests positive (Hawkins [10], Jobe [13] and/or Neer [25]), 2 out of 4 resistance tests painful (full can (thumb up) abduction at 90°, resisted abduction at 0°, resisted external or internal rotation with the arm adducted) and pain with palpation of the supraspinatus and/ or infraspinatus tendon insertion [8]. The exclusion criteria were: demonstration of partial or full ruptures of the rotator cuff by technical investigation (either ultrasound or MRI), history of shoulder surgery, shoulder fracture or dislocation, traumatic onset of the pain, osteoarthritis, frozen shoulder, traumatic glenohumeral instability or shoulder nerve injuries. Patients with concomitant disorders, such as cervical pathology or systemic musculoskeletal disease, were also excluded from the study. No physical therapy nor corticosteroid injections could have been received within 2 months prior to the study.

The Committee on Ethics of Ghent University approved the study and informed consent was obtained from each subject.

Intervention

The *TT group* performed two traditional rotator cuff strengthening exercises at home: internal and external rotation resisted with an elastic band (Thera-Band, The Hygienic Corporation, Akron, Ohio). (Figure 2 (appendix)) Each exercise was performed once a day for 3 sets of 10 repetitions. Patients were instructed to perform the exercises at a speed of 6"/repetition (2" concentric phase, 2" isometric phase and 2" eccentric phase). Color of the band was chosen so that the patient did not experience significantly more pain during the exercise than at rest. Load was increased by changing color of the elastic band as soon as pain decreased.

The *TT+ET group* performed the same exercises as the TT group and in addition to that a heavy load eccentric exercise. The eccentric phase of full can (thumb up) abduction in the scapular plane was performed with a dumbbell weight. (Figure 3 (appendix)) Patients were instructed to perform the eccentric phase at a speed of 5"/ repetition. Three sets of 15 repetitions were performed twice a day.[1] Starting position of the eccentric phase at full scapular abduction had to be pain free and if not, patients were advised to stretch out the arm at a slightly lower degree of scapular abduction. Dosing the eccentric exercises was based on the pain monitoring model [34,35]. Three conditions had to be met:

1. During the last set of 15 repetitions the patient should feel pain exceeding the pain at rest but no more than a score of 5 on the VAS (0-10) is allowed.
2. Pain after the exercise should not exceed 5 on the VAS and should have subsided the following morning.
3. Pain should not increase from day to day.

Whenever the pain was no longer present during the last set of repetitions, dumbbell weight was increased with 0,5kg.
All patients completed a daily log book to record pain during the exercises and adverse events.

Physiotherapy treatment sessions were firstly aimed at correcting some important factors that could contribute to subacromial impingement and prohibit good performance of the home exercises. Composition of this treatment was based on previous reviews [17,32]. A detailed description of these treatment components can be found in table 6 (appendix). Secondly, these sessions were aimed at correcting performance of the exercises, increasing load and emphasizing the importance of adherence to the home exercises.
No other strengthening exercises were allowed to be added to the program and participants were requested not to seek other forms of treatment during the trial.

Outcomes and Follow-up
All tests were completed at the laboratory of the Department of Rehabilitation Science and Physiotherapy of Ghent University. This investigator could not be blinded to treatment group.

A hand-held dynamometer (HHD; CompuFet; Hoggan health Industries inc, West Jordan, Utah, USA) was used to measure *isometric strength*. Hand-held dynamometry has been shown to exhibit acceptable reliability when tested on patients with strength deficits (ICC ranging from 0.78 to 0.85) [5,22]. The device was calibrated prior to commencing the study and was used at low threshold to record strengths larger than 2.7N with a sensitivity of 0.9N.
During all tests, patients were seated without back support and with feet flat on the ground,. With the non-tested arm they grasped the chair to stabilize themselves. Strength to abduction was measured at 3 arm positions: 0°, 45° and 90° of abduction in the scapular plane. These positions were verified using an Acumar™ digital inclinometer (model ACU360, Lafayette Instrument Co.; Lafayette, IN). At 0° of abduction, the arm was along the body with the elbow flexed 90° and the lower arm pointing in anterior direction. The HHD was placed against the lateral epicondyle. At 45° and 90° of abduction the arm was in a full can position with the elbow extended and the HHD was placed at the radial distal part of the lower arm. External and internal rotation strength were measured with the arm along the body, the elbow flexed 90° and the lower arm again pointing forward. The HHD was placed against the dorsal distal part of the lower arm. Three maximal isometric contractions of 5 seconds duration were performed in each direction. Standardized verbal encouragement was given during isometric strength measurements. There was a rest period of 30" between trials. Peak torque of each trial was registered. For further analyses, peak torque was averaged over these three trials.

Patients filled in the SPADI questionnaire to evaluate *pain and function*. This questionnaire is a self-administered, shoulder specific index consisting of 13 items, divided into two subscales, pain and function with responses to each item scored on a 10 point scale. The SPADI score has shown high test-retest reliability (ICC 0.95) in patients with rotator cuff tendinopathy and high responsiveness to change [22,23]. All items were summed and averaged to obtain scores out of 100. Higher scores indicate more pain and disability.

Patients rated their subjective *perception of improvement* of their shoulder pain as "improved", "not changed" or "worse". If they selected "improved" or "worse", the amount of change was scored on a 5 point scale (very little change, little change, some change, a large change, a very large change). "No change" equaled a score of 0, "better" was scored between 1 and 5 and "worse" between -1 and -5.

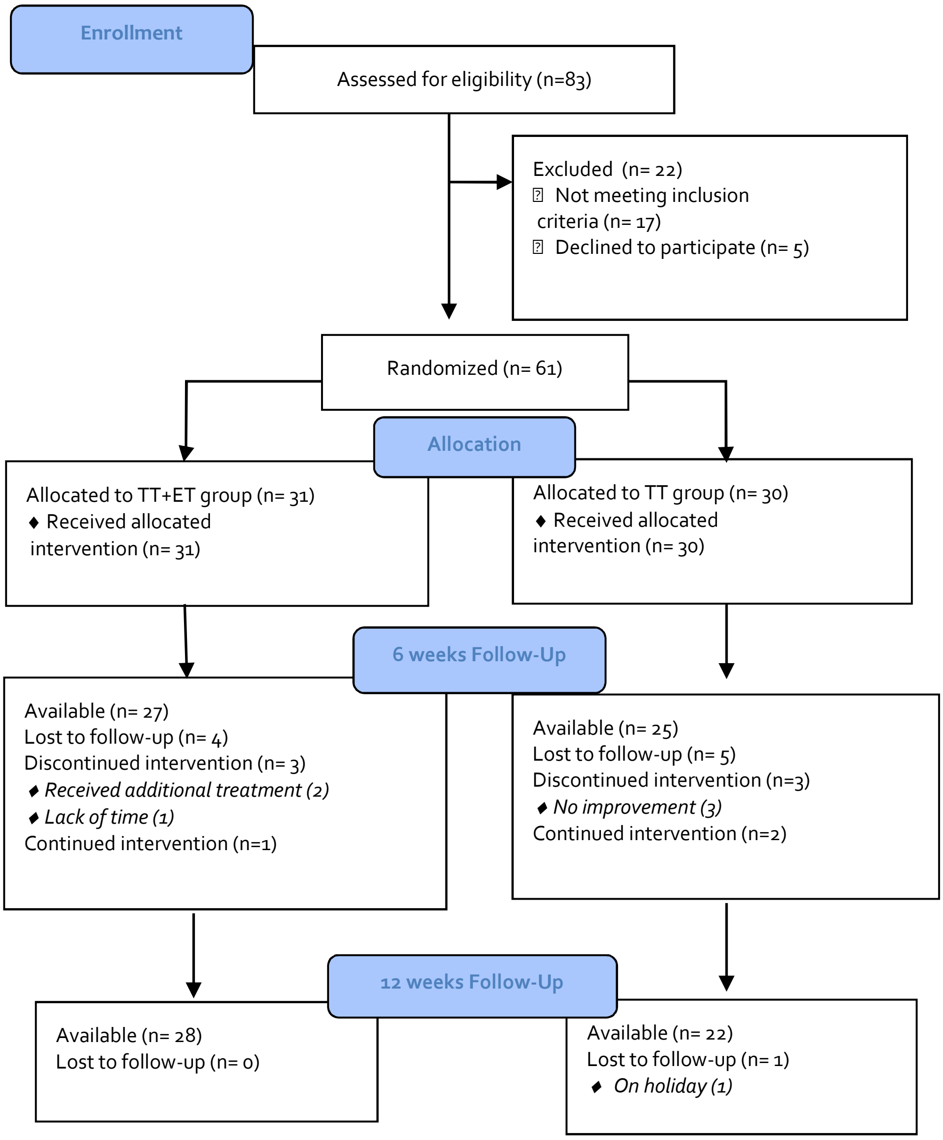
Statistical Analysis

Data were analyzed using SPSS Statistics 19 (SPSS Inc., Chicago, IL). A level of 5% was used to determine significant differences. Intention to treat principle was respected and all patients were included in analysis as randomized. Anthropometrics and baseline outcome were compared between groups with independent sample t-tests and a Chi-square test. Evolution of outcome measures over the three time points was analyzed for both groups using linear regression modeling with adjustment for baseline outcome levels. To determine treatment effect of the intervention over time, within-group effect sizes were calculated using Cohen's d coefficient ($\frac{Mean\ at\ w12 - Mean\ at\ week\ 0}{(SD\ w12 + SD\ w0)/2}$). In this equation effect size is expressed as a function of standard deviation. For example, an effect size of 0.4 reflects a difference between means of 0.4 of one standard deviation. An effect size less than 0.2 was considered small, around 0.5 moderate and greater than 0.8 large. Difference in progression between groups was analyzed using linear regression modeling with adjustment for baseline outcome levels. To determine the importance of the difference in progression between groups, between-group effect sizes were calculated as $\frac{Mean\ ET - Mean\ TT}{(SD\ ET + SD\ TT)/2}$. Model assumptions were checked by plotting obtained and expected residuals. Patients self-rated perception of improvement scores after 6 and after 12 weeks of treatment were compared between groups with chi-square tests.

RESULTS

Flow of participants is illustrated in figure 1. In total 83 patients were assessed for eligibility. Of these, 61 were included and randomly assigned to the TT+ET group (n=31) and the TT group (n=30). At the 6th week, 85% and at the 12th week 82% of included patients were available for assessment. Reasons for discontinuing the intervention are detailed in figure 1.

Figure 1. Participants flow diagram



Anthropometrics of both groups are presented in table 1. Groups did not differ significantly in any of them. Group data for all outcome measures at baseline and at 6 and 12 weeks after the start of treatment are presented in table 2 (SPADI and isometric strength). Improvement over time with corresponding within-group effect sizes are presented in table 3 and differences in improvement over 12 weeks between the TT+ET and TT group and the corresponding between-group effect sizes are presented in table 4.

Both groups showed an overall significant increase of isometric strength over time in direction of *abduction at 0°* (p<0.001) *and 45°* of scapular abduction (p<0.001) and in direction of *external* (p<0.001) *and internal rotation* (p=0.038). Post hoc tests (table 3) demonstrated significant increase of strength from 0 to 6 weeks but not from 6 to 12 weeks for abduction and external rotation strength. Internal rotation strength was only significantly increased in both groups when evaluated over the whole 12 week period (TT+ET group: p=0.038; TT group: p=0.006). Treatment effect on isometric strength to abduction at 0 and 45° and isometric strength to external and internal rotation was not significantly different between groups. (Table 4)

Isometric strength to *abduction at 90°* of abduction increased significantly in the TT+ET group after 12 weeks of treatment (Mean difference= 14.7N (19.7), p<0.001, within-group effect size= 6.2). (Table 3) In the TT group this strength was not significantly increased after 12 weeks (Mean difference= 5.1N (19.8), n.s., within-group effect size=0.6). The TT+ET group had a 15% higher gain in isometric strength at 90° after 12 weeks than the TT group (p=0.033), with respect to baseline values, with a between-group effect size of 0.7. (Table 4)

In both groups, *pain and function*, measured with the SPADI score, improved significantly over time (p<0.001). Post hoc tests showed a decreased SPADI score after 6 (p<0.001) and after 12 weeks (p<0.001). (Table 3) When comparing between groups, improvement of the SPADI score was not significantly different. (Table 4) Eighty-five per cent of patients in the TT+ET group and 89% in the TT group achieved a reduction in the SPADI score of minimum 10 points, which has been previously reported to indicate a clinically important improvement [38].

Patients self-rated *perception of improvement* was not significantly different in the TT+ ET and the TT group both at 6 weeks and at 12 weeks after the start of the intervention. (Table 5) No patients had the impression that their shoulder got worse than prior to treatment.

Table 1 Anthropometrics of the eccentric and traditional training group. (Mean (SD))

Anthropometrics			
	TT+ET (n=31)	**TT (n=30)**	**p-value**
Age (years)	40.16 (12.91)	39.43 (13.05)	.827
Height (cm)	169.56 (10.40)	169.46 (8.52)	.969
Body Mass (kg)	70.08 (14.27)	69.40 (10.26)	.831
BMI (kg/m²)	24.24 (3.24)	24.14 (3.84)	.972
Gender F:M	16:15	20:10	.059

Abbreviations: ET, eccentric training; TT, traditional rotator cuff training; BMI, Body Mass Index; F, Female; M, Male.

Table 2 Covariate-adjusted means for outcome at baseline, at 6 and at 12 weeks after start of the intervention*

	Groups					
	Week 0		**Week 6**		**Week 12**	
Outcome	**TT+ET**	**TT**	**TT+ET**	**TT**	**TT+ET**	**TT**
SPADI	42.01 (10.97)	44.30 (11.45)	25.40 (11.85)	17.68 (11.96)	16.95 (11.38)	14.54 (11.72)
Isom F abd 0°	127.9 (27.61)	123.18 (28.04)	150.78 (27.59)	142.69 (27.49)	154.26 (27.62)	147.05 (27.24
Isom F abd 45°	71.22 (12.30)	68.19 (12.27)	79.68 (12.00)	81.70 (11.96)	81.64 (12.22)	83.48 (11.81)
Isom F abd 90°	64.74 (12.64)	63.02 (12.71)	74.80 (12.31)	72.46 (12.34)	78.02 (12.54)	70.02 (12.21)
Isom F ext rot	82.89 (12.53)	83.39 (12.87)	94.34 (12.21)	90.47 (12.48)	96.02 (12.44)	92.65 (12.34)
Isom F int rot	121.71 (17.93)	118.99 (18.18)	126.48 (17.56)	123.15 (17.45)	128.98 (17.94)	125.03 (17.17)

Abbreviations: Isom F, Isometric Strength; abd, abduction; ET, eccentric training; TT, traditional rotator cuff training.

*Values are mean of groups (SD, adjusted for baseline scores, from linear mixed model. Isometric Strength in Newton.

Table 3 Covariate-adjusted mean differences within groups

	Differences within groups over time†												**Within Group Effect Size**	
Out-come	**Week 0 to week 6**				**Week 6 to week 12**				**Week 0 to week 12**				**Week 6 to week 12**	
	TT+ET	**p-value**	**TT**	**p-value**	**TT+ET**	**p-value**	**TT**	**p-value**	**TT+ET**	**p-value**	**TT**	**p-value**	**TT+ET**	**TT**
SPADI	17.08 (14.08)	<.001 *	24.06 (14.40)	<.001 *	7.50 (14.66)	.008 *	1.64 (14.44)	1.00	25.69 (15.79)	<.001 *	27.03 (19.52)	<.001 *	2.28	2.60
Isom F abd 0°	26.25 (26.76)	.016 *	19.51 (26.55)	<.001 *	9.65 (36.72)	1.00	-0.15 (36.36)	1.00	31.45 (32.24)	.005 *	17.28 (38.19)	<.001 *	0.95	0.85
Isom F abd 45°	11.11 (13.87)	.013 *	12.13 (13.60)	<.001 *	3.80 (13.17)	1.00	-0.09 (13.06)	1.00	12.82 (16.00)	.001 *	12.45 (18.96)	<.001 *	0.85	1.29
Isom F abd 90°	11.60 (13.82)	.002 *	9.46 (13.79)	.007 *	4.47 (13.02)	.788	-4.13 (13.01)	1.00	14.70 (19.74)	<.001 *	5.09 (19.76)	.059	6.15	0.55
Isom F ext rot	12.12 (14.19)	.001 *	8.60 (14.68)	.020 *	1.78 (10.53)	1.00	2.52 (10.73)	1.00	13.15 (16.12)	<.001 *	10.17 (18.63)	.002 *	1.05	0.71
Isom F int rot	12.15 (21.56)	.182	5.59 (21.48)	.261	8.14 (18.73)	1.00	3.41 (18.69)	.386	18.08 (24.76)	.038 *	7.33 (24.73)	.006 *	0.40	0.33

Abbreviations: Isom F, Isometric Strength; abd, abduction; ET, eccentric training; TT, traditional rotator cuff training.
†Values are mean difference within groups over time (SD). Isometric Strength in Newton. Positive values indicate improvement.
*The mean difference is significant at the ,05 level

Table 4 Covariate-adjusted mean differences between groups

Outcome	Difference between groups in progression from 0 to 12 weeks† (TT+ET group – TT group)	p-value	Between-group Effect Size
SPADI	1.34 (-6.97 to 9.65)	0.706	0.21
Isom F abd 0°	14.17 (-8.75 to 37.09)	0.203	0.26
Isom F abd 45°	0.37 (-9.68 to 10.43)	0.708	-0.16
Isom F abd 90°	9.61 (-0.68 to 19.90)	0.033*	0.68
Isom F ext rot	2.97 (-6.70 to 12.64)	0.490	0.27
Isom F int rot	10.74 (-4.12 to 25.61)	0.144	0.23

Abbreviations: Isom F, Isometric Strength; abd, abduction; ET, eccentric training; TT, traditional rotator cuff training.

†Values are mean difference between groups (95% CI) in progression between 0 and 12 weeks. Isometric Strength in Newton. Positive values favor the eccentric training group.

*** The mean difference is significant at the ,05 level**

Table 5 Patients self-rated perception of improvement at 6 and 12 weeks after the start of the intervention (% of group)

	6 weeks follow-up				12 weeks follow-up			
	TT+ET		TT		TT+ET		TT	
	N	% of total group	N	% of total group	N	% of total group	N	% of total group
0 (no change)	2	6.7%	2	7.4%	0	0.0%	0	0.0%
1 (very small improvement)	0	0.0%	4	14.8%	1	3.7%	0	0.0%
2 (small improvement)	3	10.0%	4	14.8%	3	11.1%	2	10.0%
3 (some improvement)	11	36.7%	7	25.9%	9	33.3%	5	25.0%
4 (large improvement)	14	46.7%	9	33.3%	9	33.3%	9	45.0%
5 (very large improvement)	0	0.0%	1	3.7%	5	18.5%	4	20.0%
Total	30		27		27		20	

Abbreviations: ET, eccentric training; TT, traditional rotator cuff training; N= number of subjects.

DISCUSSION

The most important finding of this study was that the TT+ET group showed a 15% higher gain in abduction strength at 90° of abduction than the TT group with a moderate between-group effect size. However, eccentric training did not result in less pain or better shoulder function than traditional rotator cuff training after 12 weeks. It was shown that both groups had significantly increased isometric strength, decreased pain and better function after 12 weeks of treatment. Moderate to large within-group effect sizes were demonstrated for all outcome variables. Although we did not include a third "no treatment" group to ascertain this, natural recovery is unlikely to explain these improvements of pain, function and strength. Other clinical trials found minimal changes over time in control groups receiving no treatment [20,21].

This is the first randomized clinical trial that investigated the effect of adding eccentric training to conservative treatment in patients with subacromial impingement. Eccentric training has shown good results in treatment of several tendon disorders. This type of exercise has been shown to increase collagen production [18], decrease neovascularization [27] and normalize the pathologic tendon structure [28]. Three studies have been published on eccentric training in patients with shoulder impingement [4,7,14]. Jonsson et al showed less pain and better function after 12 weeks of eccentric training in patients with impingement [14]. Main differences with our eccentric exercise were the lower dosage and the use of the empty can position in the study of Jonsson and colleagues. It has been shown that the empty can position, being internal rotation in an abducted position, narrows the subacromial space and exercising in this position could further impinge the rotator cuff tendons [29]. Moreover, Reinold et al have shown that the full can exercise is best to maximize supraspinatus activity with the least amount of deltoid muscle activity [30]. Bernhardsson et al showed decreased pain and better function after 12 weeks of eccentric rotator cuff training [4]. The exercises were performed in side-lying and aimed for infraspinatus and supraspinatus but further details on performance are lacking. Recently, Camargo et al investigated the effect of eccentric isokinetic training (abduction from 20° to 80°) in 20 patients with shoulder impingement. Pain and disability had significantly decreased after 6 weeks but isokinetic variables were only moderately changed after the intervention. The volume of their eccentric training program (3x10, twice a week, 6 weeks) was much lower than in the present study (3x15, twice a day, 12 weeks) so this could have accounted for smaller changes over time in the isokinetic strength evaluations in the study of Camargo et al. A limitation of this study is the inability to transfer the results to clinical practice as isokinetic devices are rarely available in this setting.

Our results are in line with the above described studies but though the TT+ET group showed a 15% higher gain in abduction strength at 90° of abduction, this made no difference for the SPADI score after 12 weeks. A difference in isometric strength of 10% is considered clinically significant [36]. As our TT+ET group performed the eccentric abduction exercise, this is evidently the reason why they had a higher strength gain compared to the TT group. Isometric full can abduction at 90° is used as a clinical test to assess supraspinatus pain and function [12,15]. To attribute the higher increase in isometric strength in this position to the supraspinatus is not appropriate since there are no data on tendon healing nor on EMG muscle activity of the supraspinatus available in this study.

There is still no consensus on the underlying mechanism of eccentric training. In patients with Achilles tendinopathy it is believed that strengthening is not the only responsible factor for clinical improvement after eccentric training [2]. Effects on neovascularization [27] and tendon properties [24] have been suggested to explain the good results. Future studies should investigate the immediate and long term effect of a heavy load eccentric exercise on specific properties of the supraspinatus muscle and tendon. Perhaps eccentric training should not be performed to improve clinical symptoms but to strengthen the tendon and restore degeneration.

It should be noted that this study might have been underpowered for detecting differences between groups in the SPADI score. Previous studies have reported a sample size of 60 patients in each group is required to detect differences in treatment effect [3,9]. Moreover, future trials should distinguish between subpopulations, based on responsible mechanism for tendinopathy [19] and accounting for age, gender and activity level. A next step, after investigating the influence of adding eccentric training, could be to compare between traditional training and eccentric training.

As both groups improved over time, traditional rotator cuff home exercises combined with physiotherapy treatment seems to have determined improvement of pain and function in our patients with subacromial impingement while adding an eccentric training program did not alter this. Rotator cuff training with an elastic band has been the standard home exercise programme for patients in our area for a long time. A loss of rotator cuff strength has been associated with upward humeral translation [11,31,33]. By strengthening the rotator cuff clinicians aim to increase downward translation of the humeral head during abduction and keep the subacromial space large enough.

It is important to mention that the largest progression was made during the first 6 weeks. Isometric strength to internal rotation was the only direction of strength in which no significant improvement was present after the first 6 weeks. The low amount of strength deficit of the painful side compared to the healthy side could give a plausible explanation for this finding. Possibly internal rotation strength was least affected.

Most improvement of pain and function also took place during these first 6 weeks. This time period might be a good guideline for therapists when to expect an effect of their treatment and for patients performing home exercises when to expect improvement.

At least three limitations must be taken into account when interpreting the results. Firstly, the treating physiotherapist and the investigator that collected data could not be blinded to treatment group so the influence of their expectations about treatment cannot be excluded. As both groups show marked improvement over time, the effect of these beliefs was probably marginal. Secondly, the lack of stratification for gender in randomization resulted in unequally distributed gender among the groups. The TT+ET group contained more men and was consequently stronger at baseline. We corrected for this difference by adjusting for baseline isometric strength values in statistical analysis. Thirdly, this study could not provide information on long term follow up of the patients so it is not clear how long improvements lasted.

The investigators standardized the intervention in a way that corresponded well with current clinical practice. This augments the clinical relevance and ability to transfer results of this study to clinical practice. The home exercises are very easy to perform and might decrease the need for hands-on physiotherapy, reducing medical costs.

CONCLUSION

It was shown that a 12 week traditional rotator cuff home training combined with 9 physiotherapy treatments was successful in increasing isometric strength and decreasing shoulder pain and dysfunction in patients with subacromial impingement. Adding heavy load eccentric training resulted in a higher gain of isometric strength at 90 ° of scapular abduction. This study supports the integration of an eccentric training program into a multimodal rehabilitation program. In addition, this study provided evidence that combining a limited amount of physiotherapy treatment session with a home exercise program is highly effective. Largest progression should be expected in the first 6 weeks of rehabilitation.

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APPENDIX

Figure 2. Resisted internal (a) and external rotation (b) with rubber band

Figure 3. Eccentric full can abduction exercise

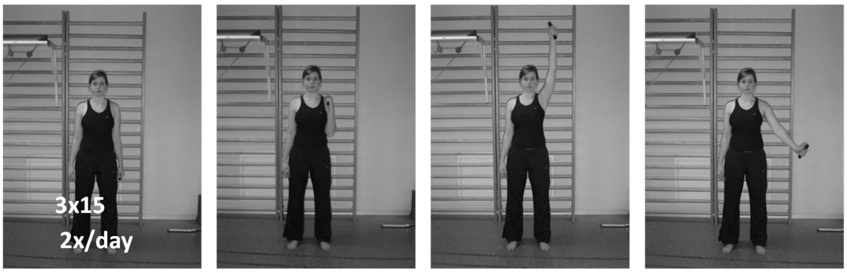


Table 6. Additional individualized physiotherapy treatment

Treatment component	Description
Information	Information on basic anatomy of the shoulder (humerus, glenoid and scapula and position of the rotator cuff tendons) and pathology of subacromial impingement
Glenohumeral mobilization	Traction perpendicular to the glenoid surface with patient lying supine Inferior translation of the humeral head with patient lying supine Posterior translation of the humeral head in internally rotated position with patient lying supine Angular mobilizations in all directions
Scapulothoracic mobilization	Mobilization of the scapula towards upward/downward rotation, posterior/anterior tilt, elevation/ depression and retraction/ protraction
Scapula setting	Motor learning with patient prone and seated, manual feedback onto coracoid process and inferior angle of the scapula or onto the lower trapezius muscle to facilitate contraction.
Posture correction	Patients were instructed to erect the thoracic spine by diminishing the curve of thoracic kyphosis. Manual feedback was provided.

Reference List

1 Alfredson H, Pietila T, Jonsson P, Lorentzon R (1998) Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. Am J Sports Med 26:360-366.

2 Allison GT, Purdam C (2009) Eccentric Loading for Achilles Tendinopathy - Strengthening or stretching? Br J Sports Med 43:276-279.

3 Bennell K, Coburn S, Wee E, Green S, Harris A, Forbes A, Buchbinder R (2007) Efficacy and cost-effectiveness of a physiotherapy program for chronic rotator cuff pathology: a protocol for a randomised, double-blind, placebo-controlled trial. BMC Musculoskelet Disord 8:86.

4 Bernhardsson S, Klintberg IH, Wendt GK (2011) Evaluation of an exercise concept focusing on eccentric strength training of the rotator cuff for patients with subacromial impingement syndrome. Clin Rehabil 25:69-78.

5 Bohannon RW (1997) Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. Arch Phys Med Rehabil 78:26-32.

6 Bot SD, van der Waal JM, Terwee CB, Van der Windt DA, Schellevis FG, Bouter LM, Dekker J (2005) Incidence and prevalence of complaints of the neck and upper extremity in general practice. Ann Rheum Dis 64:118-123.

7 Camargo PR, Avila MA, Alburquerque-Sendin F, Asso NA, Hashimoto LH, Salvini TF (2012) Eccentric training for shoulder abductors improves pain, function and isokinetic performance in subjects with shoulder impingement syndrome: a case series. Rev Bras Fisioter 16:74-83.

8 Cools AM, Cambier D, Witvrouw EE (2008) Screening the athlete's shoulder for impingement symptoms: a clinical reasoning algorithm for early detection of shoulder pathology. Br J Sports Med 42:628-635.

9 Engebretsen K, Grotle M, Bautz-Holter E, Sandvik L, Juel NG, Ekeberg OM, Brox JI (2009) Radial extracorporeal shockwave treatment compared with supervised exercises in patients with subacromial pain syndrome: single blind randomised study. BMJ 339:3360.

10 Hawkins RJ, Kennedy JC (1980) Impingement syndrome in athletes. Am J Sports Med 8:151-158.

11 Hurschler C, Wulker N, Mendila M (2000) The effect of negative intraarticular pressure and rotator cuff force on glenohumeral translation during simulated active elevation. Clin Biomech (Bristol , Avon) 15:306-314.

12 Itoi E, Kido T, Sano A, Urayama M, Sato K (1999) Which is more useful, the "full can test" or the "empty can test," in detecting the torn supraspinatus tendon? Am J Sports Med 27:65-68.

13 Jobe FW, Moynes DR (1982) Delineation of diagnostic criteria and a rehabilitation program for rotator cuff injuries. Am J Sports Med 10:336-339.

14 Jonsson P, Wahlstrom P, Ohberg L, Alfredson H (2006) Eccentric training in chronic painful impingement syndrome of the shoulder: results of a pilot study. Knee Surg Sports Traumatol Arthrosc 14:76-81.

15 Kelly BT, Kadrmas WR, Speer KP (1996) The manual muscle examination for rotator cuff strength. An electromyographic investigation. Am J Sports Med 24:581-588.

16 Khan KM, Cook JL, Bonar F, Harcourt P, Astrom M (1999) Histopathology of common tendinopathies. Update and implications for clinical management. Sports Med 27:393-408.

17 Kuhn JE (2009) Exercise in the treatment of rotator cuff impingement: A systematic review and a synthesized evidence-based rehabilitation protocol. J Shoulder Elbow Surg 18:138-160.

18 Langberg H, Ellingsgaard H, Madsen T, Jansson J, Magnusson SP, Aagaard P, Kjaer M (2007) Eccentric rehabilitation exercise increases peritendinous type I collagen synthesis in humans with Achilles tendinosis. Scand J Med Sci Sports 17:61-66.

19 Lewis JS (2009) Rotator cuff tendinopathy. Br J Sports Med 43:236-241.

20 Lombardi I, Jr., Magri AG, Fleury AM, Da Silva AC, Natour J (2008) Progressive resistance training in patients with shoulder impingement syndrome: a randomized controlled trial. Arthritis Rheum 59:615-622.
21 Ludewig PM, Borstad JD (2003) Effects of a home exercise programme on shoulder pain and functional status in construction workers. Occup Environ Med 60:841-849.
22 MacDermid JC, Ramos J, Drosdowech D, Faber K, Patterson S (2004) The impact of rotator cuff pathology on isometric and isokinetic strength, function, and quality of life. J Shoulder Elbow Surg 13:593-598.
23 MacDermid JC, Solomon P, Prkachin K (2006) The Shoulder Pain and Disability Index demonstrates factor, construct and longitudinal validity. BMC Musculoskelet Disord 7:12.
24 Mahieu NN, McNair P, Cools A, D'Haen C, Vandermeulen K, Witvrouw E (2008) Effect of eccentric training on the plantar flexor muscle-tendon tissue properties. Med Sci Sports Exerc 40:117-123.
25 Neer CS (1972) Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. J Bone Joint Surg Am 54:41-50.
26 Neer CS (2005) Anterior acromioplasty for the chronic impingement syndrome in the shoulder. 1972. J Bone Joint Surg Am 87:1399.
27 Ohberg L, Alfredson H (2004) Effects on neovascularisation behind the good results with eccentric training in chronic mid-portion Achilles tendinosis? Knee Surg Sports Traumatol Arthrosc 12:465-470.
28 Ohberg L, Lorentzon R, Alfredson H (2004) Eccentric training in patients with chronic Achilles tendinosis: normalised tendon structure and decreased thickness at follow up. Br J Sports Med 38:8-11.
29 Reinold MM, Escamilla RF, Wilk KE (2009) Current concepts in the scientific and clinical rationale behind exercises for glenohumeral and scapulothoracic musculature. J Orthop Sports Phys Ther 39:105-117.
30 Reinold MM, Macrina LC, Wilk KE, Fleisig GS, Dun S, Barrentine SW, Ellerbusch MT, Andrews JR (2007) Electromyographic analysis of the supraspinatus and deltoid muscles during 3 common rehabilitation exercises. J Athl Train 42:464-469.
31 Royer PJ, Kane EJ, Parks KE, Morrow JC, Moravec RR, Christie DS, Teyhen DS (2009) Fluoroscopic assessment of rotator cuff fatigue on glenohumeral arthrokinematics in shoulder impingement syndrome. J Shoulder Elbow Surg 18:968-975.
32 Seitz AL, McClure PW, Finucane S, Boardman III DN, Michener LA (2011) Mechanisms of rotator cuff tendinopathy: Intrinsic, extrinsic, or both? Clinical Biomechanics 26:1-12.
33 Sharkey NA, Marder RA (1995) The rotator cuff opposes superior translation of the humeral head. Am J Sports Med 23:270-275.
34 Silbernagel KG, Thomee R, Thomee P, Karlsson J (2001) Eccentric overload training for patients with chronic Achilles tendon pain--a randomised controlled study with reliability testing of the evaluation methods. Scand J Med Sci Sports 11:197-206.
35 Thomee R (1997) A comprehensive treatment approach for patellofemoral pain syndrome in young women. Phys Ther 77:1690-1703.
36 Tyler TF, Nahow RC, Nicholas SJ, McHugh MP (2005) Quantifying shoulder rotation weakness in patients with shoulder impingement. J Shoulder Elbow Surg 14:570-574.
37 Van der Windt DA, Koes BW, de Jong BA, Bouter LM (1995) Shoulder disorders in general practice: incidence, patient characteristics, and management. Ann Rheum Dis 54:959-964.
38 Williams JWJr, Holleman DRJr, Simel DL (1995) Measuring shoulder function with the Shoulder Pain and Disability Index. J Rheumatol 22:727-732.

General Discussion

1. SUMMARY AND CLINICAL IMPLICATIONS OF THE RESULTS

PART I. MECHANISMS ASSOCIATED WITH ROTATOR CUFF TENDINOPATHY

1.1 Proprioception in patients with rotator cuff tendinopathy

The *first aim* of this thesis was to further investigate the role of proprioception in patients with rotator cuff tendinopathy. (Chapter 1)
Dysfunction of motor control in patients with rotator cuff tendinopathy is obvious. A change in kinematics of the scapulothoracic and glenohumeral joint and a change in muscle activity patterns and muscle force balance compared with healthy subjects supports this strongly.[54;64] Proprioception forms the basis to make every movement we perform accurate and successful. In patients with rotator cuff tendinopathy deficient kinesthesia and joint position sense were determined previously.[1;42;58] The third modality of proprioception, force sensation, was investigated for the first time in our study presented in chapter 1.

Thirty-six patients clinically diagnosed with rotator cuff tendinopathy and 30 healthy subjects performed an internal and external rotation force reproduction test in which they were asked to reproduce a target as accurate as possible. Surprisingly, no difference between patients and healthy subjects for relative error (magnitude of error relative to the target) and coefficient of variance (smoothness of produced force) was shown. This implies that despite the presence of shoulder pathology, patients were capable of accurately exerting force aiming at a set target force and to do this with a smooth contraction without many fluctuations. **Constant error** (magnitude of error accounting for direction of error) however **differed between groups. Patients with rotator cuff tendinopathy overestimated the target** while healthy subjects underestimated the target. As overshooting a target was shown previously after experimentally induced pain, muscle fatigue and muscle damage, it is possible that this finding is the result of rotator cuff tendinopathy.[10;29;71;72] Rehabilitation programs should take this into account. Implications of this study could be sought in dosing of rotator cuff strength training exercises in patients with impingement. Possibly internal and external rotation strength training should not be dosed maximally but slightly below the maximum as it was seen that patients overshoot the force needed to perform the task. Moreover, physiotherapists should pay attention to compensatory strategies which might be an expression of overshooting. A possible compensatory strategy might be the preferred use of global muscles like the pectoralis major and latissimus dorsi, instead of local rotator cuff muscles because of pain. This change in muscle recruitment strategy from the use of local to global muscles was previously shown in patients with other musculoskeletal complaints like low back pain and is thought to occur as a result of pain inhibition.

1.2 Acromiohumeral distance in overhead athletes

Overhead athletes often suffer from shoulder pain as a result of rotator cuff tendinopathy. Repetitive impingement of the rotator cuff tendons during overhead throwing is believed to be the main trigger for rotator cuff tendinopathy in this population. When the shoulder muscles become fatigued, like for example after a long tennis game, shoulder kinematics change and this is hypothesized to further contribute to subacromial impingement. Moreover, certain shoulder adaptations, like glenohumeral internal rotation loss, are clinically believed to have a decreasing effect on the subacromial space. Though these clinical assumptions are plausible, too little research is available to provide evidence based support.

Therefore, the *second aim* of this dissertation was to increase understanding of the size and behavior of the subacromial space in an overhead athlete population.(Chapter 2, 3 and 4) Subacromial space was imaged with ultrasound. The acromiohumeral distance (AHD) (shortest distance from the most inferolateral part of the acromion to the humeral head) was used as a 2-dimensional measure for subacromial space.(Figure 1) In agreement with previous studies[20;56] **good test-retest reliability** of this measurement was shown which supports the use of this technique to quantify the subacromial space.(Chapter 2)

Figure 1. Acromiohumeral distance measurement: subject positioning and probe placement (left) and landmarks of acromiohumeral distance (right)

Three questions were addressed to provide information on the influence of training, the influence of overhead throwing fatigue and the influence of posterior shoulder tightness on the AHD:

1.2.1 What is the influence of training on the AHD in overhead athletes? (Chapter 2)

The results of the second study of this dissertation indicated that **the AHD is larger at the dominant compared with the non-dominant side** in female overhead athletes. This applies to both the elite and recreational athletes. When comparing female elite and recreational athletes, it was shown that the **AHD** is even **larger in elite compared with recreational athletes** .

Only two other studies compared the AHD between dominant and non-dominant limbs. Leong et al. also demonstrated a larger acromion-greater tuberosity distance at the dominant side in volleyball players but also in non-athletes.[38] In contrast, Cholewinski et al. found no difference for the acromion-greater tuberosity distance between limbs in a healthy non-athletic population.[13] The group of Cholewinski et al. was older (mean 57 years) than the group of Leong et al. (mean 22 years). This brings to mind that a higher general daily physical activity level could be associated with a larger AHD. This hypothesis is also supported by our finding that the AHD was larger in elite female handball players, who performed significantly more hours of sports per week compared with recreational female athletes.

Three previous studies compared athletes with non-athletes. Wang et al. found a larger AHD in elite college baseball players compared with controls.[70] Leong et al. also showed a trend for larger acromion-greater tuberosity distance in volleyball players compared with non-athletes.[38] This further supports the hypothesis that a higher physical activity level is associated with a larger AHD. Silva et al. on the other hand, found a smaller AHD in their tennis players compared with non-athletes.[63] It could have played a role that they performed measurements with the forearm pronated and the shoulder internally rotated.

The results of our study confirmed that the AHD reduces significantly from 0° to 45° abduction and from 45° to 60° of abduction. This is in agreement with the results of Desmeules et al[20] and Silva et al[63]. The **amount of reduction of the AHD relative to the initial AHD**, was **not significantly different between the dominant and non-dominant side**. Comparing the amount of reduction of the AHD between elite and recreational athletes revealed significantly **less reduction in elite athletes** when abducting the arm from neutral to 45° of abduction. Silva et al. showed more reduction in tennis players with scapular dyskinesia compared with tennis players without dyskinesia.[63] A trend for more reduction of the AHD during abduction from 0° to 45° was also observed in patients with subacromial impingement compared with a healthy population.[20]

Implications from this study should be formulated with caution as no longitudinal research was performed. A larger AHD at the dominant side compared with the non-dominant side, a larger AHD in athletes compared with controls and in elite athletes compared with recreational athletes, supports the idea that the AHD could be related to physical activity level. From results of previous studies in patients with rotator cuff pathology and athletes with scapular dyskinesis it appears that having less reduction during abduction is a positive finding.[20;63] Whether the larger AHD at the dominant side occurs due to adaptation to overhead sports activities and general activity level, or is rather inherent and the reason why they are uninjured athletes, remains unclear. Moreover it remains unclear how this is related to rotator cuff tendon thickness. A thicker tendon at the dominant side might offset the advantage of a larger AHD. Our findings may not yet be applied to male overhead athletes as our group consisted of only female athletes.

1.2.2 What is the influence of overhead throwing shoulder fatigue on the AHD? (Chapter 3)

The shoulder relies very much on the muscles surrounding it for proper kinematics. The scapular muscles, mainly the trapezius and the serratus anterior, play an important role in moving the scapula towards upward rotation, posterior tilt and external rotation during abduction.[4;27] This is crucial to lift the acromion and to avoid impingement.[35] On the other hand, the rotator cuff muscles play an important role to resist the superior pull of the deltoid onto the humeral head.[55] This is in turn believed to avoid impingement of the subacromial structures. When these muscles are fatigued from overhead sports activities it is plausible that this may have an influence on the AHD.[12;14;15;21;22;44;65] Therefore, a study was performed in which 29 overhead athletes were fatigued with an exercise that resembles an overhead throwing motion.(Figure 3)

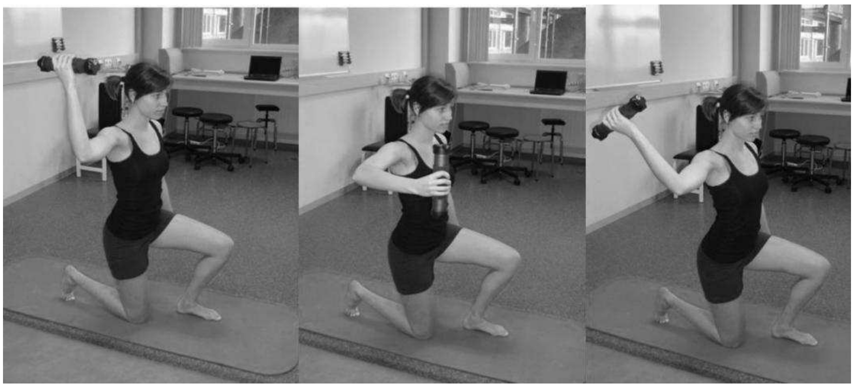


Figure 3. Shoulder muscle fatiguing protocol

This study showed that despite to what is intuitively believed**, the AHD becomes larger after a shoulder muscle fatigue protocol when the arm is actively held at 45° and 60° of abduction.** At the same positions, the scapula was in a significantly more upwardly rotated, posteriorly tilted and externally rotated position after fatigue. As these directions are believed to enlarge the subacromial space[2;62], the increased AHD found after fatigue probably relates to the scapular position alterations found. This implies that humeral translation either didn't change or didn't change enough in an upward direction to decrease the subacromial space.

These observed changes could reflect a compensatory strategy with increased scapular motion relative to glenohumeral motion during active abduction to compensate for the fatigued glenohumeral muscles. The results of this study raise doubt as to whether shoulder fatigue is associated with development of subacromial impingement of the rotator cuff in overhead athletes. Though maybe shoulder fatigue, as a result of overhead throwing might not give rise to subacromial impingement, it might still be related to rotator cuff tendinopathy by inducing overload of the tendons and initiating intratendinous degeneration.

As to rehabilitation of overhead athletes with impingement, the results of this study might indicate that the use of our overhead throwing exercise with an XCO-trainer® could be appropriate for early functional return-to-sports training. This exercise is currently used in practice mainly at end stage rehabilitation. Moreover, one might infer from the results that shoulder muscle endurance training in this position should not be feared in patients with subacromial impingement. Then again, physiotherapists should pay attention to the direction of scapular compensation during this exercise as it is possible that the shoulder reacts differently in the presence of pain.

1.2.3 What is the influence of posterior shoulder tightness on the AHD? (Chapter 4)

Glenohumeral internal rotation deficit (GIRD) was shown by Wilk et al. to be a risk factor for shoulder injuries in overhead athletes.[73] GIRD is thought to at least partially result from posterior shoulder tightness.[48;68;69] Increased superior and anterior humeral head translation was shown in cadavers with a tightened posterior capsule.[24] Scapular kinematics have also shown to be altered in the presence of GIRD but the direction of these changes (decreased or increased) remains unclear due to inconsistent results.[7;36;66;67]

From our study presented in chapter 4 it appeared that the **AHD was smaller** at rest and at 45° and 60° active abduction at the dominant side of healthy **overhead athletes with GIRD** of more than 15° compared with the non-dominant side. Though differences were small, they might relate to a change of subacromial pressure in the presence of posterior shoulder tightness, as was previously shown by Muraki et al.[45;46] The implication from this study is that GIRD is associated with a minimally smaller AHD compared with the contralateral side. This strengthens the belief that GIRD could give rise to subacromial impingement and hence rotator cuff tendinopathy. However, it remains unclear if this smaller AHD at the dominant side in athletes with GIRD is associated with a higher risk for rotator cuff tendinopathy caused by subacromial impingement.

PART II. CONSERVATIVE TREATMENT OF PATIENTS WITH ROTATOR CUFF TENDINOPATHY

1.3 Posterior shoulder stretching in overhead athletes

Both healthy overhead athletes and subjects with rotator cuff tendinopathy associated with subacromial impingement have been shown to regularly suffer from posterior shoulder tightness and GIRD. Stretching the posterior shoulder to restore internal rotation ROM is suggested in management of subacromial impingement in overhead athletes. Moreover, stretching has been recommended to prevent shoulder injuries in overhead athletes and enhance sports performance. It is not clear if stretching also affects glenohumeral and scapular kinematics and therefore if this would alter the size of the subacromial space. We investigated the change of AHD after a 6 week sleeper stretch program in healthy overhead athletes.

It is striking that **after performing the sleeper stretch** (Figure 2) at the dominant side daily for 6 weeks, the **AHD** at rest and at 45° and 60° active abduction **significantly increased**. No change in AHD was seen at the non-dominant side of the stretch group and at both sides of the control group after 6 weeks.

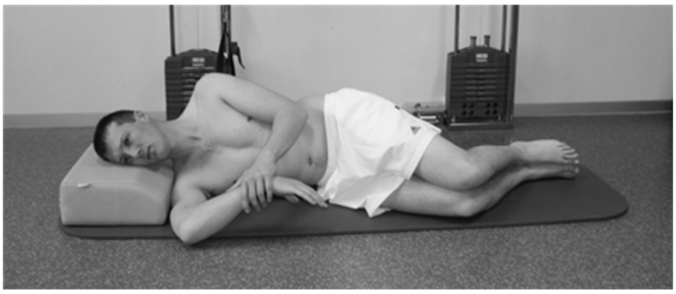


Figure 2. Sleeper stretch

From this study we can infer that GIRD can be reduced by a 6 week sleeper stretch program and this reduction is associated with an increase of the AHD. If the amount of increase of the AHD after stretching is enough to diminish the risk for impingement cannot be decided based on the results of our study. The use of the sleeper stretch in healthy athletes to oppose the loss of internal rotation range of motion as an adaptation to overhead throwing and to preserve the available subacromial space is supported by the results of this study. Furthermore, the use of the sleeper stretch in patients with subacromial impingement should be promoted to decrease posterior shoulder tightness and increase the subacromial space.

1.4 Scapular muscle balance training: which exercises to prescribe?

The study in chapter 5 wanted to answer the question: "Which variations of the knee push up plus are appropriate for restoring UT/SA balance and how is scapular muscle activity affected by the kinetic chain during the knee push up plus exercise?"

Patients with subacromial impingement have shown decreased EMG activity of the serratus anterior (SA) muscle and increased EMG activity of the upper trapezius (UT) muscle.[39;54] The challenge is to find exercises with high SA activity opposed to low UT activity in order to restore this scapular muscle imbalance.
Ludewig et al. have shown previously that UT/SA was low during standard push up plus and KPP exercises.[40] We investigated scapular muscle EMG activity during the KPP and 6 variations in 32 healthy subjects.(Figure 4)

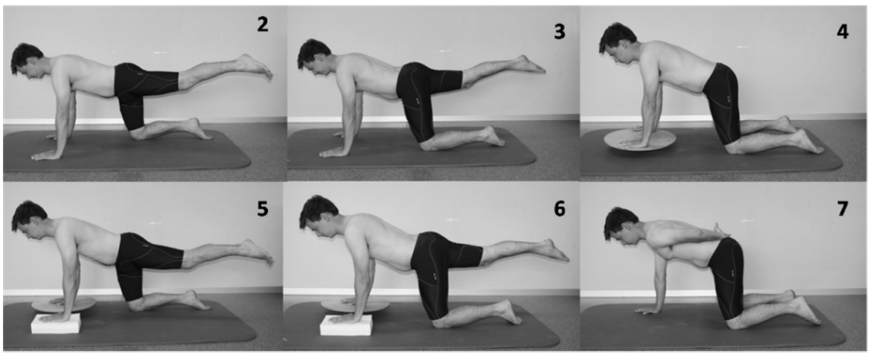


Figure 4. Six variations on the knee push up plus exercise

Based on the results of this study, four exercises with low UT/SA (between 0.40 and 0.54) can be selected for rehabilitation of intermuscular balance in patients with subacromial impingement:

1. Standard KPP
2. KPP with homolateral leg extension
3. KPP with homolateral leg extension on a wobble board
4. One-handed KPP

These exercises all require twice as much activity of the SA compared with the UT and are therefore suitable for patients with subacromial impingement. The KPP with homolateral leg extension (Figure 5, exercise 3) showed the highest mean SA EMG activity in combination with the lowest UT/SA ratio.

KPP with heterolateral leg extension without and with a wobble board (Figure 5, exercises 2 and 5) were the only exercises in which UT/SA was not favorable (UT/SA 1.00 and 1.56 respectively). These exercises should therefore not be used to restore UT/SA balance.

During both daily and sports activities the shoulder doesn't move in isolation but cooperates with the trunk and lower limbs in specific movement patterns.[43] In shoulder exercise therapy leg extension is often incorporated to simulate these patterns and to train the shoulder muscles to work together with trunk and lower limb muscles. As discussed above, KPP with **homolateral leg extension** required the **highest SA activity**. Muscle chains have been described by Myers et al. and Porterfield and DeRosa.[49;57] The SA is believed to be part of the anterior flexion chain. This chain runs from the heterolateral hip flexion musculature, through the heterolateral internal oblique abdominals and homolateral external oblique abdominals to the SA. Muscle fibers of all muscles in this chain are in line with each other. When the homolateral leg is extended, the heterolateral leg should bear more weight which likely requires higher stabilizing hip flexion muscle activity. In this view the anterior flexion chain supports the higher SA activity observed in this study.

In contrast, KPP with **heterolateral leg extension** without and with a wobble board required the **lowest SA activity**. Extending the heterolateral leg requires hip extension muscle activity and inhibits the antagonistic hip flexion musculature. This might disrupt the anterior flexion chain resulting in the observed low SA muscle activity.

The opposite was shown for lower trapezius (LT) activity. This was generally low in all KPP variations so these exercises are not appropriate for strengthening LT. Strikingly, the KPP exercises with **heterolateral leg extension** showed the **highest LT activity**. Extending the heterolateral leg requires gluteus maximus activity. This muscle is part of the posterior extension chain which runs from gluteus maximus to the thoracolumbar fascia and to the heterolaterale LT. Like this, heterolateral hip extension could have facilitated the observed increase of LT activity. This has some interesting implications for stabilization training in patients with shoulder instability related pathology. Closed chain exercises are prized because they are believed to enhance cocontraction of the rotator cuff which stabilize the glenohumeral joint. When physiotherapists aim to facilitate the LT, the heterolateral leg should be extended. When stability training in combination with SA activity is preferred, homolateral leg extension might be superior.

1.5 Eccentric training in patients with rotator cuff tendinopathy

The study presented in chapter 6 was designed to determine the effect of physiotherapy combined with rotator cuff home training and the superior value of adding a heavy load eccentric home training program.

Previous studies had shown good results with eccentric training in patients with subacromial impingement.[6;11;30] Due to the absence of a control group, it remained unclear if eccentric training would augment efficacy of current techniques in conservative rehabilitation.

Sixty-one patients were included in our study and randomly allocated to the TT (traditional rotator cuff strength training) group or the TT+ET (traditional rotator cuff strength training + eccentric training) group. The TT group performed an internal and external rotation exercise with a rubber band once a day. The TT+ET group performed the same exercises added with heavy load eccentric full can scapular abduction (Figure 5). All exercises were performed at home for 12 weeks. Meanwhile, patients attended 9 physiotherapy treatment sessions.

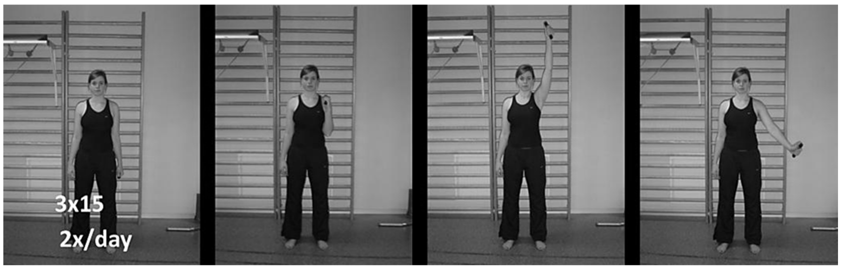


Figure 5. Eccentric exercise program for patients with rotator cuff tendinopathy

In agreement with previous studies, **pain** was shown to be **significantly decreased** and **shoulder function improved** in the group that performed the **eccentric training program** (TT+ET group).

Compared with the TT group that only performed traditional rotator cuff training, outcome was **equally good** concerning pain and shoulder function.

In both groups isometric shoulder force was also shown to be increased. The **increase of isometric force to abduction at 90° scapular abduction** was **significantly larger in the TT+ET group**. The TT group showed no significant increase of abduction force at this position. As Kelly et al[34] showed that at 90° scapular abduction contribution of the supraspinatus is larger than that of the agonists, it is possible that better function of supraspinatus muscle and tendon was present in the TT+ET group compared with the TT group. Perhaps eccentric training should not be performed to improve clinical symptoms in patients with rotator cuff tendinopathy associated with subacromial impingement, but to improve supraspinatus function and increase tendon strength.

Jonsson et al[30] and Bernhardsson et al[6] did not evaluate shoulder force after eccentric training. Camargo et al[11] tested isokinetic abduction force after their isokinetic eccentric training program without additional treatment and showed small significant changes in peak torque, total work and acceleration time. The effect sizes of the significantly increased isokinetic peak torque in the study of Camargo et al. (Cohen's d=0.18-0.22) were generally much lower than the effect sizes of the significantly increased isometric peak torques in the TT+ET group of this study (Cohen's d= 0.85-6.15). This might mean that to increase shoulder force, performing an eccentric training program in addition to a general rehabilitation program (physiotherapy treatment + rotator cuff training) is superior to an isolated eccentric training program. The relation between the rotator cuff and the shoulder joint is different from that between for example the patella tendon and the knee joint because of the tunnel through which the rotator cuff tendons pass. Results on eccentric training of lower limb studies cannot be simply transferred to the rotator cuff. A proper rehabilitation program should address both extrinsic factors related to subacromial impingement and intrinsic factors related to tendon degeneration. Like this physiotherapists should aim to increase the subacromial space and simultaneously make the tendons stronger and less prone to degeneration.

The results of our study showed excellent results of home training combined with a minimal amount of physiotherapy treatment sessions. This concept in which the vital role of a physiotherapist is to give professional advice, follow up progress and fine-tune the training program while the patient takes equal responsibility by performing the exercises to the best, is very attractive in view of augmenting the efficiency of physiotherapy and lowering heath care costs. Based on our study we can state that patients with impingement should expect most improvement of pain, function and strength within 6 weeks.

2. STRENGTHS AND LIMITATIONS OF THE THESIS

This dissertation entails both strengths and limitations which are important to allow considerate interpretation. This section looks at issues with measurement techniques that were chosen, the ability or inability to define underlying mechanisms of the results and the causal relation of the results of our studies.

2.1 Measurement techniques

Measurement techniques that were chosen to investigate and answer the research questions of this dissertation bring about some strengths but also limitations. In particular, ultrasound imaging, surface EMG and electromagnetic motion tracking with skin base receivers are discussed in this part.

To evaluate the subacromial space, *ultrasound imaging* was chosen in chapter 2, 3 and 4. A limitation of this imaging technique is that it is 2-dimensional and does not take into account what may occur at other aspects or volume of the subacromial space. Previous studies using radiography to investigate the subacromial space however have shown concurrent validity of ultrasound imaging.[3] Radiography has in turn demonstrated a high correlation with MRI measures of the subacromial space.[59]

The advantages offered by ultrasound imaging, namely that it is safe, easy to use, portable, relatively low-priced and more accessible than for example MRI and radiography, make it preferable over other imaging techniques.[32] In addition, it is suitable for examining tissues both statically and dynamically with the individual in various positions.[9] Tissues can be examined while subjects are seated, which allows the shoulder and especially the scapula to move free in space in contrast to a supine position.

It must be noted that imaging the subacromial space with ultrasound during abduction is limited to 60° because of acoustic shadowing from the bony acromion beyond 60°.[20] The rotator cuff tendons have then rotated medially under the acromion and can no longer be visualized in most subjects. Ultrasonographic measurement of the AHD beyond 60° abduction would then no longer be relevant. Graichen et al. did show that the minimal AHD passes right through the supraspinatus tendon at 30° and 60° of abduction in contrast to the minimal AHD at 90° of abduction that is located laterally of the supraspinatus.[23] This supports the relevance of measuring the AHD between 0° and 60° of abduction.

To standardize these abduction angles and to make sure that the subjects did not lower the arm during measurements a belt was used as previously described in a study of Desmeules et al.[20] Verbal instructions to not pull on the belt were explicitly given to the subjects. Moreover it was visually controlled that the belt was not pressed into the soft tissues of the lower arm resulting from abduction or external rotation contraction during measurement.

To monitor 3-dimensional scapular motion in the study presented in chapter 3, the *Fastrak electromagnetic motion tracking device* with skin base receivers was used. In order to completely describe scapular motion, the use of 3-dimensional measurement technique is preferable over 2-dimensional clinical measurements often used in literature.[39;41;50]
As we used the non-invasive surface acromial method to register scapular position, skin motion artifacts may have occurred. However, Karduna et al. validated the surface acromial method with the bone based technique with pins into the scapula and concluded that this method is well suited for capturing the essence of motion patterns, especially below 120°.[33] As our maximal abduction degree was 60°, it is likely that there was not much skin displacement. ISB recommendations for bony landmarks, local coordinate systems and Eular angle sequence were used to standardize the measurement protocol.[75]
Because of the large amount of interindividual variability in scapular position we did not use mean absolute position of the scapula to investigate the influence of fatigue. The mean of this absolute position would represent a subject that doesn't exist and is not relevant. Instead, we used the amount of change of motion around the 3 axes before and after fatigue.

In Chapter 5 *surface EMG* was used to examine scapular muscle activity during the KPP and variations. EMG involves recording the action potentials that activate skeletal muscle fibers. Although this technique provides valuable information regarding muscle activity, some limitations must be understood for proper interpretation.
First, recorded muscle activity may not represent activity of the entire muscle. The electrodes on the skin surface only detect the electrical current of the muscle fibers within the pick-up area of the electrodes.[5] On the other hand, neighboring muscles may produce a significant amount of EMG activity that is detected by the local electrodes, which is called cross-talk.[74] Given that the electrodes were not displaced during the study protocol, detected differences between our exercises are not influenced by a different detection area.
Second, an inherent problem of surface EMG with dynamic investigations is the change of distance between the signal origin site and the signal detecting electrode because of skin displacement. This could have influenced the EMG signal. Fine wire EMG overcomes this problem. However, fine wire EMG measures a rather small selection of muscle fibers EMG while

surface EMG is believed to provide a more global impression when examining large muscle groups such as the trapezius and serratus anterior.[18] Precautions were taken by following SENIAM prescriptions for electrode placement, electrode spacing and skin preparation.[25] In addition, recommendations of previous investigations that used surface EMG to analyze scapular muscle activity were respected.[16;19;37;40]

2.2 Underlying mechanisms?

The studies of this thesis should be seen as first steps in certain directions which need further elaboration. Several interesting findings have been observed, but the underlying mechanisms remain hypothetical. This restriction comes along with the choice of measurement techniques and the study design in some of our investigations.
In the studies of chapter 2 and 4, the findings on AHD cannot be assigned to an altered scapular or humeral head position. This is precisely the strength of chapter 3 as we included 3-dimensional scapular position measurement in this study to monitor the changes and link them afterwards to the changes of the AHD.
In chapter 1 the underlying mechanism of altered force sensation is also not clear. Force sensation results from a combination of peripheral sensation of tension and central sensation of effort.[28] However, these aspects are rather difficult to objectify.

When discussing the results of the study in chapter 5, the theory of muscle chains is applied to the KPP exercises and fits perfectly well with the muscle activity observed.[49;57] It should be noted however that we could not assure that this theory provides the underlying mechanism for increased SA activity when the homolateral leg is extended and increased LT activity when the heterolateral leg is extended. Muscle activity was not evaluated over this whole muscle chain.

Finally, the underlying mechanism for the results of the study in chapter 6 needs some consideration. As a first step to investigate the effect of adding an eccentric training program to conservative rehabilitation it is important to evaluate clinical outcome like pain, function and force. We showed a higher strength gain to abduction at 90° abduction in our eccentric training group. We cannot yet ascribe this to the supraspinatus as we are not in possession of such data. Neither can we rule on the impact of eccentric training on supraspinatus muscle structure and biology (e.g. fatty degeneration, cross-sectional area) and rotator cuff tendon healing (e.g. collagen type and orientation, neovascularization). These aspects have been related to the success of eccentric training previously in patients with Achilles tendinopathy.[51;52]

2.3 Cause or consequence?

To decide upon cause and consequence, a longitudinal prospective follow-up study design is needed. Our studies enhance understanding of associations but up to now we are unable to formulate conclusions about the cause-consequence relation of the findings.

In healthy female overhead athletes it was shown that the AHD is larger on the dominant side and even larger in elite female athletes.(Chapter 2) Possibly this is the consequence of adaptation of the dominant side to a combination of daily and sports activity demands onto the shoulder. The more hours training a week and the higher the level of competition, the more the shoulder adapts to these activities. However, observation of adaptations in the shoulders of healthy overhead athletes varies widely. Some identified adaptations that might indeed increase the AHD[17;47], while others found adaptations that might decrease the AHD[8;38;53]. In addition, no information was obtained on the presence of adaptations in our subjects.

On the other hand, the finding of a larger AHD in our study might not be the consequence of adaptation but rather the reason why they are injury free athletes. Similarly, the larger AHD could be partly the reason why the elite athletes are successful at this high competition level. This would imply that having a larger AHD would be associated with a lower risk for injury and better performance level. Based on our study we cannot define this causal relation.

To get a better idea of the relation between shoulder adaptations in overhead athletes we performed a second study in athletes that were selected based on a 15° of more internal rotation deficit.(Chapter 4) It was shown that the athletes with glenohumeral internal rotation loss displayed a smaller AHD at the dominant side. Based on these finding we can only ascertain an association between internal rotation loss and a smaller AHD at the dominant side. However, this was overcome to some degree by showing a change after performing the sleeper stretch. This strengthens the belief that the internal rotation loss was at least partly the cause for the decreased AHD.

The same remark should be made for the observation that patients with subacromial impingement overestimate force during internal and external rotation force reproduction tests.(Chapter 1) It is not clear yet if this is the cause or the consequence of rotator cuff tendinopathy. The rotator cuff muscles which were the subject of our testing protocols show a lot of functional and structural changes in patients with rotator cuff tendinopathy. A reduction in size and number of muscle spindles and Golgi tendon organ was demonstrated previously after injury and disuse.[31;60] In this view, our findings could have been the consequence of rotator cuff pathology.

Alternatively, altered force sensation could have been the cause of rotator cuff tendinopathy or could have sustained the pathologic process in our subjects. When the amount of force used during daily activities is higher than needed, this could relate to overuse of the rotator cuff. Furthermore, using too much force might alter glenohumeral or scapulothoracic kinematics and compromise the subacromial space.

3. DIRECTIONS FOR FUTURE RESEARCH

3.1 Proprioception in patients with rotator cuff tendinopathy

The results of our study in chapter 1 indicated overestimation but preserved control of force in patients with rotator cuff tendinopathy. Besides isometric external and internal rotation force reproduction, concentric and eccentric external and internal rotation force reproduction should be investigated in patients with rotator cuff tendinopathy. Hortobagyi et al. have shown deficient accuracy and steadiness of eccentric and concentric force rather than isometric force in patients with knee osteoarthrosis.[26] Adequate control of these dynamic submaximal muscle forces is especially important in activities of daily living.

Another interesting direction for research is the influence of physical therapy rehabilitation on proprioception. This could enhance understanding the role of proprioception in patients with rotator cuff tendinopathy. In clinical practice specific proprioception training, including for example position-reposition, mirroring arm movement and force reproduction exercises, is predominantly used in rehabilitation of patients with shoulder instability related pathology. It is not clear whether proprioception training would offer added value in patients with rotator cuff tendinopathy. Therefore, an important question that needs to be answered is:

- What is the impact of a multimodal rehabilitation program with and without specific proprioception training in patients with rotator cuff tendinopathy on the three submodalities of proprioception?

3.2 Acromiohumeral distance in overhead athletes

In a first study (chapter 2) we showed that the AHD was larger at the dominant side compared with the non-dominant side and in elite compared with recreational female athletes. Additional research is needed in male overhead athletes and in other sports disciplines to determine if these results can be applied across gender and sports discipline. Future studies should also identify if a correlation exists between general activity level and size of the subacromial space.

Together with the studies of Silva et al[63] and Leong et al[38], the findings of our study (chapter 4) support the belief that shoulder adaptations (scapular dyskinesis, decreased ER/IR ratio and GIRD) could be related to narrowing of the subacromial space and ultimately subacromial impingement. Prospective studies in overhead athletes are needed to answer the following questions:

- What is the incidence of subacromial impingement related pathology in overhead athletes with and without marked scapular dyskinesis, decreased ER/IR ratio or GIRD?
- What is the change of incidence of impingement related pathology in athletes, included in a prevention program comprised of scapular stabilization exercises, external rotator strengthening exercises and/or posterior shoulder stretching?

These studies will provide insight into the relation between these adaptations and the risk for impingement and between prevention programs and a reduced risk.

3.3 Scapular muscle balance training

We selected 4 variations of the KPP exercise with a low UT/SA which are appropriate for restoring scapular muscle balance in patients with subacromial impingement. Cools et al. previously reported a selection of 4 exercises with low UT/MT and UT/LT.(COOLSetal) Research regarding the effect of these exercises in patients with subacromial impingement should be the next step. Balance between UT and SA, MT and LT muscle activity before and after this exercise program is specifically of interest. Moreover, the impact of any change of scapular muscle balance on scapular kinematics and ultimately on the size of the subacromial space should be determined as this is the clinical rationale for including these exercises in rehabilitation. In conclusion, future studies should answer the following question:

- What is the effect of a scapular exercise program in patients with subacromial impingement related rotator cuff tendinopathy on pain and function, scapular inter- and intramuscular balance, scapular kinematics and the size of the subacromial space?

3.4 Eccentric training

Jonsson et al. were the first to investigate the effect of an eccentric training program in patients with subacromial impingement.[30] Bernhardsson et al. and Camargo et al. performed similar studies but with varying eccentric exercises.[6;11] We were the first to investigate conservative rehabilitation with and without eccentric training in patients with subacromial impingement and rotator cuff tendinopathy. Although eccentric training resulted in higher strength gain, there were no significantly better results for pain and shoulder function. It is notable that some of our subjects subjectively felt decreasing pain immediately throughout performing an eccentric exercise while some did not report this feeling. This strengthened our clinical belief in the value of heavy load eccentric training. In future studies subjects with rotator cuff tendinopathy should be divided into two groups, based on the causing mechanism (either dominant extrinsic subacromial impingement or dominant intrinsic tendon degeneration) as proposed by Seitz et al.[61] It is plausible that patients with a dominant intrinsic degeneration mechanism are better served with eccentric training than patients with a dominant extrinsic compression mechanism.

The clinical rationale for applying eccentric training in patients with tendinopathy is to oppose an appropriate load onto the tendon to pursue tendon healing and strengthening. In this view, a future study should include other outcome measures related to rotator cuff tendon healing, like for example tendon thickness and vascularity. A long term follow-up moment should be added to investigate whether eccentric training can decrease recurrence rates of rotator cuff tendinopathy complaints.

4. CONCLUSIONS FOR CLINICAL PRACTICE

Rotator cuff tendinopathy is a very common shoulder pathology in overhead athletes. Subacromial impingement is believed to be an important mechanism causing this tendinopathy. Our findings on AHD, a measure for the size of the subacromial space, in overhead athletes should be added to the findings of Silva et al. and Leong et al. as schematically presented in figure 6.[38;63]

We showed that the AHD at the dominant side of female overhead athletes is larger than at the non-dominant side and larger in higher level athletes compared with recreational athletes. A relation with physical activity demands on the shoulder is plausible.
Moreover, we observed that after overhead throwing fatigue in healthy overhead athletes, the scapula compensates to preserve the AHD. However, the presence of pronounced dominant shoulder adaptations in overhead athletes, like the loss of internal rotation range of motion, scapular dyskinesis and rotator cuff muscle imbalance with a lower external to internal rotation force ratio (ER/IR), negatively influences the AHD. We showed that internal rotation loss is combined with a smaller AHD at the dominant side. However, this seems to be reversible as we observed that the AHD increases after a sleeper stretch program. Silva et al. showed more reduction of the AHD when marked scapular dyskinesis is present.[63] Leong et al. showed a positive correlation between AHD and external rotation force and between AHD and ER/IR with smaller AHD in the presence of lower external rotation force and lower ER/IR ratio.[38]

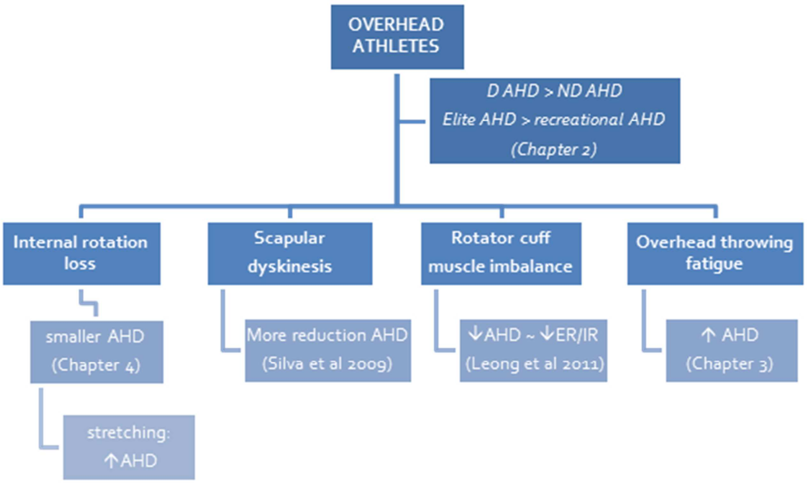


Figure 6. Size and behavior of the acromiohumeral distance in overhead athletes and the relation with sports specific shoulder adaptations

Based on these results we can suggest that a good shoulder injury prevention program in overhead athletes should entail:

- Scapular orientation exercises
- Scapular strengthening exercises focused at lower trapezius and serratus anterior
- External rotation strengthening
- Posterior shoulder stretching by use of for example the sleeper stretch.

As to patients with rotator cuff tendinopathy, we can recommend that proper rehabilitation should incorporate eccentric training into a multimodal approach addressing all factors associated with narrowing of the subacromial space. A limited amount of *physiotherapy sessions* should, depending on each individual patient, focus on:

- Providing the patient with information
- Correcting forward head and rounded shoulder posture
- Correcting scapular position and motion
- Stretching the posterior shoulder soft tissues
- Improving articular hypomobility
- Establishing a home exercise program

The home exercise program should entail **rotator cuff exercises** as a core.(Chapter 6) We showed that physiotherapy combined with rotator cuff strengthening decreases pain, improves function and increases strength. Physiotherapists should pay attention to proper performance of these exercises. We found that patients overestimate internal and external rotation force.(Chapter 1) We should be aware of this fact when dosing the exercises and guarantee the use of the intended muscles, the rotator cuff muscles, with the opposed load. It could be interesting to improve appreciation of the exerted muscle force in advance through exercises like for example to contract up to the maximum in 4 seconds and gradually release, to contract maximally and contract with half of this effort or a quarter of this effort,...

When the scapula is involved in pathology, **scapular strengthening exercises** should be performed. Four exercises can be selected based on our study (Chapter 5) with low UT/SA: standard KPP, KPP with homolateral leg extension with and without a wobble board and one-handed KPP. When complaints are associated with minor instability, these exercises can also be used for **closed chain shoulder stability training**. When lower trapezius muscle activity is intended, the heterolateral leg should be extended and when serratus anterior activity is intended, the homolateral leg should be extended during KPP.

In case the posterior shoulder soft tissues are shortened, these should be stretched by use of for example the **sleeper stretch**.(Chapter 4) Performing this stretch might decrease subacromial pressure in the affected shoulder.

The superior value of adding a **heavy load eccentric training** lies in a higher increase of abduction strength at 90° abduction.(Chapter 6) Adding eccentric training may not be superior to reduce symptoms but may improve supraspinatus function and tendon degeneration.(Chapter 6) Physiotherapists should not fear for increased pain by eccentric training. Our dosing method, based on the pain monitoring model, proved very useful for patients to monitor the eccentric exercises at home.

Finally **sports specific exercises** should be integrated when rehabilitating an overhead athlete. Plyometric internal and external rotation at 90° abduction using an XCO-trainer® might be an appropriate exercise as it requires acceleration of the internal rotators and deceleration of the external rotators similar to an overhead throwing motion.(Chapter 3)

Physiotherapists must be aware that the largest progression should be expected within the first 6 weeks of treatment. In appendix a concrete protocol for physiotherapy rehabilitation in patients with rotator cuff tendinopathy and associated subacromial impingement can be found with practical examples.

Reference List

1. Anderson VB, Wee E. Impaired joint proprioception at higher shoulder elevations in chronic rotator cuff pathology. *Arch Phys Med Rehabil* 2011;92:1146-1151.
2. Atalar H, Yilmaz C, Polat O, Selek H, Uras I, Yanik B. Restricted scapular mobility during arm abduction: implications for impingement syndrome. *Acta Orthop Belg* 2009;75:19-24.
3. Azzoni R, Cabitza P, Parrini M. Sonographic evaluation of subacromial space. *Ultrasonics* 2004;42:683-687.
4. Bagg SD, Forrest WJ. A biomechanical analysis of scapular rotation during arm abduction in the scapular plane. *Am J Phys Med Rehabil* 1988;67:238-245.
5. Basmajian JV, De Luca CJ. Muscles alive: their functions revealed by electromyography. 1985. 5th ed. Baltimore, Md: Williams and Wilkins.
Ref Type: Serial (Book,Monograph)
6. Bernhardsson S, Klintberg IH, Wendt GK. Evaluation of an exercise concept focusing on eccentric strength training of the rotator cuff for patients with subacromial impingement syndrome. *Clin Rehabil* 2011;25:69-78.
7. Borich MR, Bright JM, Lorello DJ, Cieminski CJ, Buisman T, Ludewig PM. Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. *J Orthop Sports Phys Ther* 2006;36:926-934.
8. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. *Sports Med* 2008;38:17-36.
9. Bureau NJ, Beauchamp M, Cardinal E, Brassard P. Dynamic sonography evaluation of shoulder impingement syndrome. *AJR Am J Roentgenol* 2006;187:216-220.
10. Cafarelli E. Force sensation in fresh and fatigued human skeletal muscle. *Exerc Sport Sci Rev* 1988;16:139-168.
11. Camargo PR, Avila MA, Alburquerque-Sendin F, Asso NA, Hashimoto LH, Salvini TF. Eccentric training for shoulder abductors improves pain, function and isokinetic performance in subjects with shoulder impingement syndrome: a case series. *Rev Bras Fisioter* 2011.
12. Chen SK, Simonian PT, Wickiewicz TL, Otis JC, Warren RF. Radiographic evaluation of glenohumeral kinematics: a muscle fatigue model. *J Shoulder Elbow Surg* 1999;8:49-52.
13. Cholewinski JJ, Kusz DJ, Wojciechowski P, Cielinski LS, Zoladz MP. Ultrasound measurement of rotator cuff thickness and acromio-humeral distance in the diagnosis of subacromial impingement syndrome of the shoulder. *Knee Surg Sports Traumatol Arthrosc* 2008;16:408-414.
14. Chopp JN, Fischer SL, Dickerson CR. The specificity of fatiguing protocols affects scapular orientation: Implications for subacromial impingement. *Clin Biomech* 2011;26:40-45.
15. Chopp JN, O'Neill JM, Hurley K, Dickerson CR. Superior humeral head migration occurs after a protocol designed to fatigue the rotator cuff: a radiographic analysis. *J Shoulder Elbow Surg* 2010;19:1137-1144.
16. Cools AM, Dewitte V, Lanszweert F et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? *Am J Sports Med* 2007;35:1744-1751.
17. Cools AM, Johansson FR, Cambier DC, Velde AV, Palmans T, Witvrouw EE. Descriptive profile of scapulothoracic position, strength and flexibility variables in adolescent elite tennis players. *Br J Sports Med* 2010;44:678-684.
18. 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;31:542-549.
19. de Araujo RC, Tucci HT, de AR, Martins J, Bevilaqua-Grossi D, de Oliveira AS. Reliability of electromyographic amplitude values of the upper limb muscles during

closed kinetic chain exercises with stable and unstable surfaces. *J Electromyogr Kinesiol* 2008.

20. Desmeules F, Minville L, Riederer B, Cote CH, Fremont P. Acromio-humeral distance variation measured by ultrasonography and its association with the outcome of rehabilitation for shoulder impingement syndrome. *Clin J Sport Med* 2004;14:197-205.
21. Ebaugh DD, McClure PW, Karduna AR. Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. *J Electromyogr Kinesiol* 2006;16:224-235.
22. Ebaugh DD, McClure PW, Karduna AR. Scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol. *J Orthop Sports Phys Ther* 2006;36:557-571.
23. Graichen H, Bonel H, Stammberger T, Englmeier KH, Reiser M, Eckstein F. Subacromial space width changes during abduction and rotation--a 3-D MR imaging study. *Surg Radiol Anat* 1999;21:59-64.
24. Harryman DT, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA. Translation of the humeral head on the glenoid with passive glenohumeral motion. *J Bone Joint Surg Am* 1990;72:1334-1343.
25. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol* 2000;10:361-374.
26. Hortobagyi T, Garry J, Holbert D, Devita P. Aberrations in the control of quadriceps muscle force in patients with knee osteoarthritis. *Arthritis Rheum* 2004;51:562-569.
27. Johnson GR, Pandyan AD. The activity in the three regions of the trapezius under controlled loading conditions--an experimental and modelling study. *Clin Biomech (Bristol , Avon)* 2005;20:155-161.
28. Jones LA. Role of central and peripheral signals in force sensation during fatigue. *Exp Neurol* 1983;81:497-503.
29. Jones LA, Hunter IW. Effect of fatigue on force sensation. *Exp Neurol* 1983;81:640-650.
30. Jonsson P, Wahlstrom P, Ohberg L, Alfredson H. Eccentric training in chronic painful impingement syndrome of the shoulder: results of a pilot study. *Knee Surg Sports Traumatol Arthrosc* 2006;14:76-81.
31. Jozsa L, Kannus P, Jarvinen TAH, Balint J, Jarvinen M. Number and morphology of mechanoreceptors in the myotendinous junction of paralysed human muscle. *Journal of Pathology* 1996;178:195-200.
32. Kane D, Grassi W, Sturrock R, Balint PV. Musculoskeletal ultrasound--a state of the art review in rheumatology. Part 2: Clinical indications for musculoskeletal ultrasound in rheumatology. *Rheumatology (Oxford)* 2004;43:829-838.
33. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. *J Biomech Eng* 2001;123:184-190.
34. Kelly BT, Kadrmas WR, Speer KP. The manual muscle examination for rotator cuff strength. An electromyographic investigation. *Am J Sports Med* 1996;24:581-588.
35. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med* 1998;26:325-337.
36. Laudner KG, Moline MT, Meister K. The relationship between forward scapular posture and posterior shoulder tightness among baseball players. *Am J Sports Med* 2010;38:2106-2112.
37. Lear LJ, Gross MT. An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. *Journal of Orthopaedic & Sports Physical Therapy* 1998;28:146-157.
38. Leong HT, Tsui S, Ying M, Leung VY, Fu SN. Ultrasound measurements on acromio-humeral distance and supraspinatus tendon thickness: Test-retest reliability and correlations with shoulder rotational strengths. *J Sci Med Sport* 2011.

39. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther* 2000;80:276-291.
40. Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. *Am J Sports Med* 2004;32:484-493.
41. 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;29:574-583.
42. Machner A, Merk H, Becker R, Rohkohl K, Wissel H, Pap G. Kinesthetic sense of the shoulder in patients with impingement syndrome. *Acta Orthop Scand* 2003;74:85-88.
43. McMullen J, Uhl TL. A kinetic chain approach for shoulder rehabilitation. *Journal of Athletic Training* 2000;35:329-337.
44. McQuade KJ, Dawson J, Smidt GL. Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. *J Orthop Sports Phys Ther* 1998;28:74-80.
45. Muraki T, Yamamoto N, Zhao KD et al. Effect of posteroinferior capsule tightness on contact pressure and area beneath the coracoacromial arch during pitching motion. *Am J Sports Med* 2010;38:600-607.
46. Muraki T, Yamamoto N, Zhao KD et al. Effects of posterior capsule tightness on subacromial contact behavior during shoulder motions. *J Shoulder Elbow Surg* 2011.
47. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Scapular position and orientation in throwing athletes. *Am J Sports Med* 2005;33:263-271.
48. Myers JB, Oyama S, Wassinger CA et al. Reliability, precision, accuracy, and validity of posterior shoulder tightness assessment in overhead athletes. *Am J Sports Med* 2007;35:1922-1930.
49. Myers TW. *Anatomy trains: Myofascial meridians for manual and movement therapists*. Edinburgh: Churchill Livingstone, 2001.
50. Nijs J, Roussel N, Struyf F, Mottram S, Meeusen R. Clinical assessment of scapular positioning in patients with shoulder pain: state of the art. *J Manipulative Physiol Ther* 2007;30:69-75.
51. Ohberg L, Alfredson H. Effects on neovascularisation behind the good results with eccentric training in chronic mid-portion Achilles tendinosis? *Knee Surg Sports Traumatol Arthrosc* 2004;12:465-470.
52. Ohberg L, Lorentzon R, Alfredson H. Eccentric training in patients with chronic Achilles tendinosis: normalised tendon structure and decreased thickness at follow up. *Br J Sports Med* 2004;38:8-11.
53. Oyama S, Myers JB, Wassinger CA, Daniel RR, Lephart SM. Asymmetric resting scapular posture in healthy overhead athletes. *J Athl Train* 2008;43:565-570.
54. Page P. Shoulder muscle imbalance and subacromial impingement syndrome in overhead athletes. *Int J Sports Phys Ther* 2011;6:51-58.
55. Parsons IM, Apreleva M, Fu FH, Woo SL. The effect of rotator cuff tears on reaction forces at the glenohumeral joint. *J Orthop Res* 2002;20:439-446.
56. Pijls BG, Kok FP, Penning LI, Guldemond NA, Arens HJ. Reliability study of the sonographic measurement of the acromiohumeral distance in symptomatic patients. *J Clin Ultrasound* 2010;38:128-134.
57. Porterfield JA, DeRosa C. Mechanical shoulder disorders. Perspectives in functional anatomy. 2004. Elsevier Science.
Ref Type: Serial (Book,Monograph)
58. Safran MR, Borsa PA, Lephart SM, Fu FH, Warner JJ. Shoulder proprioception in baseball pitchers. *J Shoulder Elbow Surg* 2001;10:438-444.
59. Saupe N, Pfirrmann CW, Schmid MR, Jost B, Werner CM, Zanetti M. Association between rotator cuff abnormalities and reduced acromiohumeral distance. *AJR Am J Roentgenol* 2006;187:376-382.

60. Scott JJA, Petit J, Davies P. The dynamic response of feline Golgi tendon organs during recovery from nerve injury. *Neuroscience Letters* 1996;207:179-182.
61. Seitz AL, McClure PW, Finucane S, Boardman III DN, Michener LA. Mechanisms of rotator cuff tendinopathy: Intrinsic, extrinsic, or both? *Clinical Biomechanics* 2011;26:1-12.
62. Seitz AL, McClure PW, Lynch SS, Ketchum JM, Michener LA. Effects of scapular dyskinesis and scapular assistance test on subacromial space during static arm elevation. *J Shoulder Elbow Surg* 2011.
63. Silva RT, Hartmann LG, Laurino CF, Bilo JP. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. *Br J Sports Med* 2010;44:407-410.
64. Struyf F, Nijs J, Baeyens JP, Mottram S, Meeusen R. Scapular positioning and movement in unimpaired shoulders, shoulder impingement syndrome, and glenohumeral instability. *Scand J Med Sci Sports* 2011;21:352-358.
65. Teyhen DS, Miller JM, Middag TR, Kane EJ. Rotator cuff fatigue and glenohumeral kinematics in participants without shoulder dysfunction. *J Athl Train* 2008;43:352-358.
66. Thomas SJ, Swanik CB, Higginson JS et al. A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. *J Shoulder Elbow Surg* 2011;20:708-716.
67. Thomas SJ, Swanik KA, Swanik CB, Kelly JD. Internal rotation deficits affect scapular positioning in baseball players. *Clin Orthop Relat Res* 2010;468:1551-1557.
68. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med* 2000;28:668-673.
69. Tyler TF, Roy T, Nicholas SJ, Gleim GW. Reliability and validity of a new method of measuring posterior shoulder tightness. *J Orthop Sports Phys Ther* 1999;29:262-269.
70. Wang HK, Lin JJ, Pan SL, Wang TG. Sonographic evaluations in elite college baseball athletes. *Scand J Med Sci Sports* 2005;15:29-35.
71. Weerakkody NS, Percival P, Canny BJ, Morgan DL, Proske U. Force matching at the elbow joint is disturbed by muscle soreness. *Somatosens Mot Res* 2003;20:27-32.
72. Weerakkody NS, Percival P, Morgan DL, Gregory JE, Proske U. Matching different levels of isometric torque in elbow flexor muscles after eccentric exercise. *Experimental Brain Research* 2003;149:141-150.
73. Wilk KE, Macrina LC, Fleisig GS et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med* 2011;39:329-335.
74. Winter DA, Fuglevand AJ, Archer SE. Crosstalk in surface electromyography: Theoretical and practical estimates. *J Electromyogr Kinesiol* 1994;4:15-26.
75. Wu G, van der Helm FC, Veeger HE et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. *J Biomech* 2005;38:981-992.

SUMMARY

Due to the high prevalence, shoulder pain is a relevant problem in health care. Rotator cuff tendinopathy is frequently the cause and it is thought to be induced by subacromial impingement because of narrowing of the subacromial space. Proper rehabilitation requires full understanding of **mechanisms associated with rotator cuff tendinopathy**.

The *first aim* of this thesis was to further explore the role of proprioception in patients with rotator cuff tendinopathy. Proprioception forms the basis to make every movement we perform accurate and successful. In patients with rotator cuff tendinopathy deficient kinesthesia and joint position sense were determined previously. We investigated the third modality, force sensation, and found preserved control but overestimation of internal and external rotation force in patients with rotator cuff tendinopathy.

Overhead athletes regularly suffer from shoulder pain as a result of rotator cuff tendinopathy and are therefore an interesting population to study. Repetitive impingement of the rotator cuff tendons during overhead throwing is believed to be the main trigger for rotator cuff tendinopathy in this population. The *second aim* of this thesis was to investigate the acromiohumeral distance (AHD, from the acromion to the humeral head), a 2-dimensional measure for subacromial space and it's behavior in overhead athletes. First, the influence of training was of interest. A larger distance was found at the dominant compared with the non-dominant side and in elite compared with recreational athletes.This might indicate that the subacromial space size is related to physical activity level. Second, the influence of shoulder muscle fatigue on the AHD was investigated. Functional muscle fatigue induced by overhead throwing was postulated to play a role in development of subacromial impingement. The shoulder joint obtains very little stability from passive structures like the capsule and the ligaments. Hence, mainly shoulder muscles are responsible for optimizing kinematics. We showed that after overhead throwing fatigue, the scapula compensates and moves to a more upwardly and externally rotated and posteriorly tilted position which resulted in an increased AHD in healthy overhead athletes. Third, the influence of posterior shoulder thightness, an adaptation frequently found in the dominant shoulder of overhead ahtletes, on the AHD was examined. Previous studies showed that posterior shoulder tightness is related to alterations of glenohumeral and scapulothoracic kinematics. The consequence of these alterations for subacromial space size remained unexplored. We showed a smaller AHD at the dominant side in a selected group of athletes with 15° or more internal rotation range of motion loss. This strenthens the belief that posterior shoulder tightness could be related to subacromial impingement.

Rehabilitation of patients with rotator cuff tendinopathy should be aimed at correcting kinematics to diminish subacromial impingement. The third aim of this thesis was to contribute to conservative treatment of patients with rotator cuff tendinopathy by further investigating three aspects of this treatment: posterior shoulder stretching, scapular muscle balance training and eccentric training.

Both healthy overhead athletes and subjects with rotator cuff tendinopathy associated with subacromial impingement have been shown to regularly suffer from posterior shoulder tightness and GIRD. Stretching the posterior shoulder to restore internal rotation ROM is suggested in management of subacromial impingement in overhead athletes. Moreover, stretching has been recommended to prevent shoulder injuries and enhance sports performance. We investigated the change of AHD after a 6 week sleeper stretch program in healthy overhead athletes and found an increased range of motion and AHD in healthy overhead athletes with posterior shoulder tightness.

To increase muscle strength is another important aim of treatment in patients with rotator cuff tendinopathy. In light of enlarging the subacromial space, obtaining correct scapular position and motion is crucial. The serratus anterior has been shown to contribute to impingement sparing kinematics of the scapula. The challenge is to find exercises that selectively activate the serratus anterior with minimal contribution of the upper trapezius to improve UT/SA muscle balance. Four variations of the knee push-up plus were found to have a low UT/SA thus appropriate for patients with rotator cuff tendinopathy. Moreover, it was shown that extension of the homolaterale leg during knee push up plus increases serratus anterior activity, while extension of the homolaterale leg increases lower trapezius activity.

Since evidence is growing on the contribution of intrinsic degeneration to development of rotator cuff tendinopathy, this should be acknowledged in treatment as well. From research on physiotherapy treatment in other tendinopathies, like for example Achilles tendinopathy, we've learned that eccentric training leads to better outcome and even regeneration of tendon tissue. Given the similarities in terms of pathology, it could be questioned if these results can be transferred to rotator cuff tendinopathy. Therefore, we examined the influence of a traditional rotator cuff training program whether or not combined with eccentric training on pain, function and isometric force. In patients with rotator cuff tendinopathy we showed that adding an eccentric training program to a multimodal rehabilitation program results in superior abduction strength gain at 90° of abduction. Moreover, adding an eccentric training program leads to equal decrease of pain and improvement of function compared with the same treatment without eccentric training.

Samenvatting

Schouderpijn is een veel voorkomende klacht in de kinesitherapeutische praktijk. Tendinopathie van de rotator cuff is hierbij een vaak gestelde diagnose. Een adequaat opgesteld behandelprogramma vereist inzicht in de **mechanismen geassocieerd met rotator cuff tendinopathie.**

Het *eerste doel* van dit doctoraat was de rol van proprioceptie bij patiënten met rotator cuff tendinopathie te onderzoeken. Proprioceptie zorgt ervoor dat beweging precies en doelgericht kan worden gestuurd. Voorgaand onderzoek toonde gestoorde houdings- en bewegingszin bij patiënten met rotator cuff tendinopathie. Wij onderzochten het derde onderdeel van proprioceptie, namelijk krachtsensatie, en vonden dat patiënten met rotator cuff tendinopathie hun endo- en exorotatie kracht vrij accuraat kunnen inschatten en stabiel overbrengen maar dat ze de neiging hebben om meer kracht te leveren dan nodig.

Bovenhandse sporters krijgen vaak te maken met rotator cuff tendinopathie geassocieerd met subacromiaal impingement en vormen bijgevolg een interessante populatie voor onderzoek. Het *tweede doel* van dit doctoraat was de grootte en het biomechanisch gedrag van de subacromiale ruimte bij bovenhandse sporters te onderzoeken.
Ten eerste werd de invloed van training op de acromiohumerale afstand (AHA, de afstand van acromion tot humerus als representatie voor de grootte van de subacromiale ruimte) nagegaan. Er werd aangetoond dat de AHA groter is aan de dominante zijde bij bovenhandse sportsters en groter is bij elite sportsters in vergelijking met recreatieve sportsters. Dit duidt mogelijks op een verband tussen fysieke activiteit en de grootte van de subacromial ruimte.
Ten tweede werd onderzocht wat de invloed is van schouderspier vermoeidheid op de AHA. De schouder is intrinsiek instabiel en hangt voornamelijk van de sturing door de schouderspieren. Vermoeidheid van deze spieren wordt verondersteld bij te dragen tot subacromiaal impingement. Echter, uit ons onderzoek konden we aantonen dat bij gezonde sporters de scapula compenseert voor deze vermoeidheid en meer opwaarts en extern roteert en posterieur tilt met als gevolg dat de acromiohumerale afstand stijgt.
Ten derde waren we geïnteresseerd in de invloed van posterieure schouderverkorting op de AHA. Dit is een adaptatie in de schouder die heel frequent gezien wordt bij bovenhandse sporters. Voorgaand onderzoek toonde reeds aan dat in aanwezigheid van posterieure schouderverkorting de glenohumerale en scapulothoracale kinematica verandert. De invloed hiervan op de AHA bleef echter onduidelijk. Bij een selectie sporters met uitgesproken glenohumeraal endorotatie deficiet aan de dominante zijde, werd in dit doctoraat een significant kleinere acromiohumerale afstand aan de dominante zijde gevonden.

De **revalidatie van patiënten met rotator cuff tendinopathie** moet gericht zijn op herstel van de kinematica om de subacromiale ruimte terug te vergroten. Het derde doel van dit doctoraat was om bij te dragen tot de kwaliteit van conservatieve behandeling door onderzoek te doen naar drie aspecten die deel uitmaken van die revalidatie: posterieure shouder stretching, scapulaire spierkrachttraining en excentrisch trainen.

In de revalidatie van patiënten met rotator cuff tendinopathie alsook in de preventie van schouderklachten bij bovenhandse sporters wordt geadviseerd om de posterieure schouder te stretchen. Uit ons onderzoek bleek dat na 6 weken stretchen met de sleeper stretch de glenohumerale endorotatie significant toeneemt alsook de acromiohumerale afstand.

Scapulaire spierkachttraining is eveneens een belangrijk onderdeel van de behandeling van patiënten met rotator cuff tendinopathie. Met het oog op het verruimen van de subacromiale ruimte is het belangrijk om een correcte scapulaire positie en beweging na te streven. De serratus anterior draagt hiertoe bij en het versterken van deze spier lijkt dan ook aangewezen. De uitdaging bestaat erin om oefeningen te vinden die geschikt zijn voor het herstellen van het scapulair intermusculair evenwicht tussen upper trapezius en serratus anterior om zo een correcte scapulaire kinematica te bevorderen. Uit ons onderzoek konden 4 oefeningen worden geselecteerd met een lage ratio UT/SA die bijgevolg geschikt zijn voor revalidatie van patiënten met rotator cuff tendinopathie. Daarnaast werd aangetoond dat strekken van het homolaterale been tijdens de knee push-up plus oefening activiteit van de serratus anterior verhoogt, terwijl strekken van het heterolaterale been activiteit van de lower trapezius verhoogt.

Naast extrinsiek subacromiaal impingement is er eveneens bewijs voor intrinsieke factoren die aanleiding geven tot intratendineuze degeneratie in de rotator cuff. Dit houdt in dat de behandeling zich mogelijks niet alleen moet richten op het wegnemen van subacromale compressie maar eveneens dient bij te dragen tot versterken van het peesweefsel. Bij Achilles tendinopathie werd aangetoond dat excentrisch trainen degeneratie van peesweefsel kan herstellen. Gezien de grote gelijkenissen op histologisch vlak tussen rotator cuff en Achilles tendinopathie kan de vraag gesteld worden of excentrisch trainen ook bij deze eerste leidt tot goede resultaten. Een laatste studie van dit doctoraat onderzocht de meerwaarde van het toevoegen van een excentrisch trainingsprogramma in de revalidatie bij patiënten met rotator cuff tendinopathie. De groep die excentrisch trainde had een grotere abductie krachtswinst wanneer de arm zich op 90° abductie bevindt. Het toevoegen van het excentrisch trainingsprogramma leidde tot even goede resultaten qua pijndaling en functieverbetering.

Appendix

Physiotherapy treatment of patients with rotator cuff tendinopathy with associated subacromial impingement should be a multimodal approach, addressing all factors that could be related to narrowing of the subacromial space. A detailed clinical examination should therefore precede treatment and identify the presence of the impairments 1 to 4, presented in the figure below. Depending on the impairments found during clinical examination, goals should set to restore them and tools should be chosen to reach this goal.
In addition to restoring factors that could narrow the subacromial space, treatment should aim to improve tendon tissue quality using eccentric exercises.

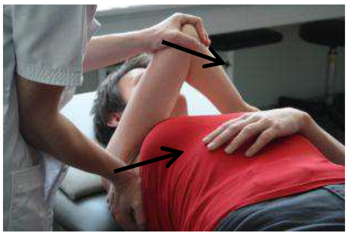
Impairment	Goal	Tool
1. Posterior shoulder stiffness	Motor Control	Manual Therapy
2. ↓ Pectoralis Minor length	↑ Soft tissue flexib.	Motor learning
3. Scapular dyskinesis	↑ Articular mobility	Stretching
4. ↓ Rotator cuff strength	↑ Muscle strength	Mobility exercises
5. Thoracic hyperkyphosis/hypomobility	Tendon regeneration	Strength training
6. ↓ Quality tendon tissue		Eccentric training

A combination of manual therapy and a comprehensive home exercise program can be advised. Below, some examples of manual therapy techniques and specific exercises are listed to reduce pain, improve motor control, increase soft tissue and articular flexibility, improve muscle strength and aim to regenerate tendon tissue in patients with rotator cuff tendinopathy associated with subacromial impingement.

Pain relief	
Manual therapy	
Glenohumeral traction in loose packed position (55° abduction, 35° horizontal adduction, neutral rotation)	
Inferior translation of the humeral head	
1. Posterior shoulder stiffness	
Manual Therapy	
Glenohumeral internal rotation at 90° forward flexion with scapular stabilization	
Dorsal glide of the humeral head in glenohumeral loose packed position	
Dorsal glide of the humeral head in glenohumeral internal rotation (hand behind back)	

Scapular retraction/posterior tilt in glenohumeral internal rotation (hand behind back)

Glenohumeral horizontal adduction with scapular stabilization



Stretching

Horizontal adduction stretch:
The arm is at 90° forward flexion and is brought towards horizontal adduction by the non-stretched side. Attention must be paid to maintaining scapular retraction to stretch the glenohumeral joint.

Sleeper stretch:
The arm is at 90° forward flexion and 90° horizontal adduction, the elbow is flexed 90°. The upper hand grasps the hand of the shoulder to be stretched and brings it downward to the floor while maintaining 90° forward flexion, 90° horizontal adduction in the shoulder and not allowing scapular elevation.

Modalities:

- 3x30"
- 1x/day during first 6 weeks
- 1x/2days during next 6 weeks

2. Shortened Pectoralis Minor

Manual therapy

Soft tissue technique:

The therapist strums perpendicularly onto the fibers of the pectoralis minor.

Stretching the pectoralis minor:

With one hand the therapist pushes the coracoid process towards the table to move the scapula towards retraction and posterior tilt, with the other hand the therapist pushes the first ribs in direction of the contralateral hip.

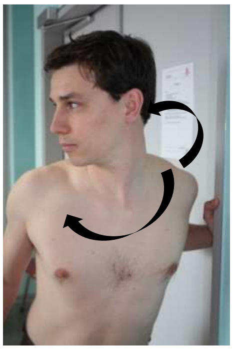
Stretching

Pectoralis minor self stretch:

The patient lies supine, bends the knees and turns them to the contralateral side of the side to be stretched. Next, the arm is brought up in a circular movement diagonally upward and pauses at each point at which stiffness is experienced. Goal is to facilitate posterior tilt and retraction of the scapula.

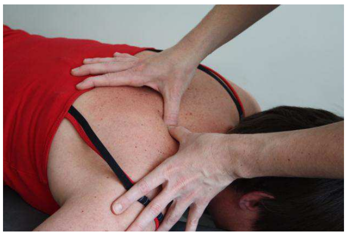
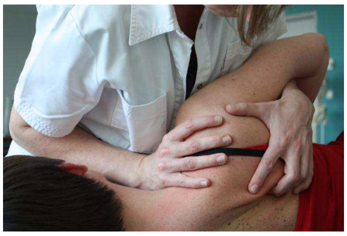
Door stretch:

The patients places the hand in a door frame at shoulder height and leans forward so that the trunk passes the door frame. Next the trunk is rotated away from the side to be stretched while scapular retraction is maintained.



Modalities:

- 3x30"
- 1x/day during first 6 weeks
- 1x/2days during next 6 weeks

3. Scapular dyskinesis	
Manual therapy	
Soft tissue technique to release adhesions around the scapula.	
Soft tissue technique to decrease upper trapezius tension: The therapist strikes with the thumb parallel between the fibers of the upper trapezius from the insertion to the origin.	
Upper trapezius/levator scapue trigger point treatment	
Scapulothoracic mobilization towards upward rotation/downward rotation, elevation/depression, protraction/retraction	
Mobilization with movement: The therapist assists the scapula towards upward rotation, posterior tilt and external rotation during forward flexion/ scapular abduction/ abduction.	

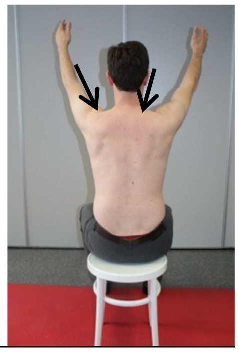
Motor learning

Scapular orientation:

The therapist learns the patient how to place the scapulae in a correct and stable position towards posterior tilt and retraction.


Upper trapezius relaxation during abduction:

The therapist learns the patient how to relax the upper trapezius during forward flexion/ scapular abduction/ abduction.

Scapular strength training

Prone retroflexion

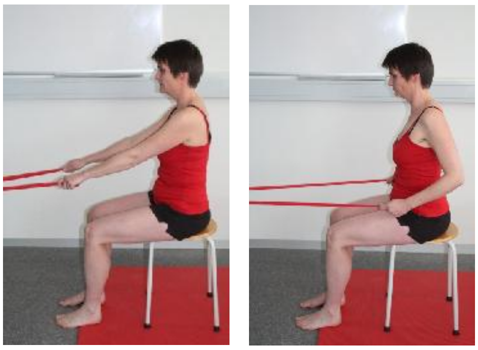
Prone horizontal abduction with external rotation

Sidelying external rotation

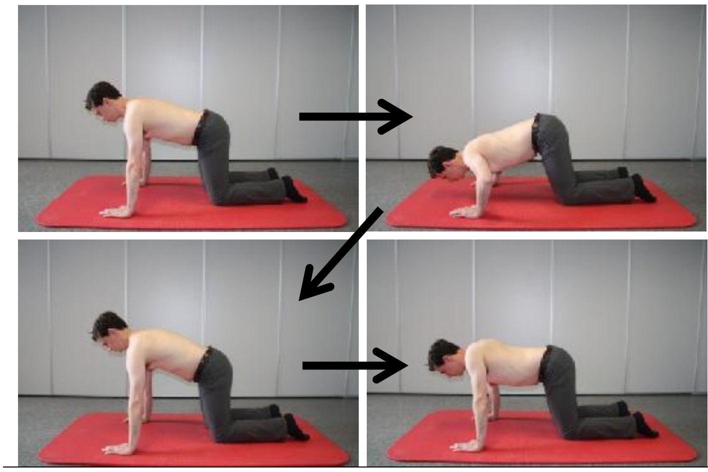
Side lying forward flexion

W-V exercise

Low row



Knee push-up plus



Knee push-up plus with homolateral leg extension (with a wobble board)

One-handed knee push-up plus

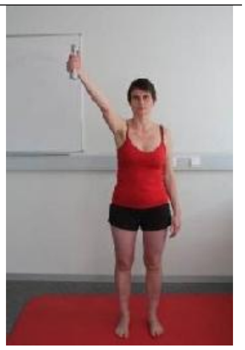
Modalities:

- Color of Theraband or dumbbell weight are chosen so that the exercise can be performed painfree
- Progression from 3x10 to 5x20 repetitions
- **1x/day**

1. **Decreased rotator cuff strength**	
Manual therapy	
Trigger point treatment infraspinatus/subscapularis/…	

Rotator cuff strength training		
External/ internal rotation in neutral position with Theraband (A towel can be placed between the trunk and elbow during external rotation to decrease deltoid activity through antagonistic adductor activity.)		
W-exercise bilateral with Theraband		
Sidelying external rotation in neutral position with dumbbell		
External/internal rotation at 90° of abduction with Theraband		

Full can abduction with dumbbell/Theraband



Modalities:

- Patients overestimate internal and external rotation force.(Chapter 1) The therapist should be aware of this fact when dosing the exercises and guarantee the use of the intended muscles, the rotator cuff muscles and not the prime movers like for example the pectoralis major, with the opposed load. Exercises that can be performed to improve appreciation of the exerted muscle force are for example:
    - Gradually contracting the external/internal rotators to maximum in 4 seconds and gradually releasing
    - Contracting maximum and contracting with half of this effort or a quarter of this effort,…
- Color of Theraband or dumbbell weight is chosen so that the exercise can be performed painfree
- Progression from 3x10 to 5x20 repetitions
- 1x/day

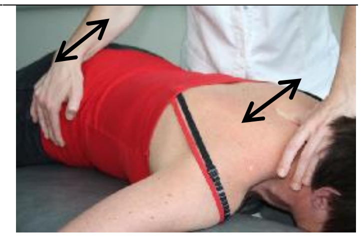
2. Thoracic hyperkyphosis/hypomobility

Manual therapy

Prone thoracic spine flexion/ extension harmonics:
Therapist places one hand on occiput and one hand on thoracic spinous process and simultaneously moves both hands rhythmically towards cranial and distal.

Prone thoracic spine rotation harmonics:

Therapist places one hand on iliac crest and the thumb of the other hand on the thoracic spinous process and alternates laterolateral rhythmic movement of both hands.



Seated mobilization:

1. Cervicothoracic junction rotation mobilization

2. Thoracic spine lateroflexion/ rotation mobilization

3. Thoracic spine extension mobilization

Motor learning

Correcting forward head and rounded shoulder posture:

Patient performs a chin tuck motion with the head and lengthens the thoracic spine.

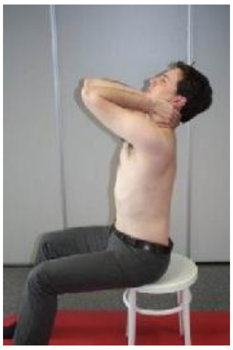
Integrate a good posture in all home exercises.

In addition, functional exercises to maintain a good posture can be performed, depending on patients' needs.

Mobility exercises

Sidelying rotation

Seated extension



Seated rotation with arm extension

Modalities:

- 3x20 repetitions
- 1x/day – 1x/2days

3. Decreased quality of tendon tissue

Eccentric training

Eccentric scapular abduction standing

Eccentric scapular abduction side-lying

Eccentric horizontal abduction side-lying

Eccentric horizontal abduction prone

Eccentric external rotation supine

Eccentric external rotation standing

Eccentric upward diagonals

Modalities:

- Color of Theraband or dumbbell weight chosen so that the exercise elicits pain during the last set of repetitions between 1 and 5 on a VAS of 10.
- Pain should have subsided one hour after performing the exercise.
- Pain should not be worse the day after.
- Pain should not increase from day to day or from week to week.
- 3x15 repetitions
- 2x/day
-

Sport specific rehabilitation	
Prone decelerating external rotation with plyoball	
Internal/ external rotation at 90° with XCO trainer	
Plyometric internal/external rotation at 90° abduction	
…	



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Annelies Maenhout

Ghent, June 2012

LIST OF ABBREVIATIONS

AHD: acromiohumeral distance
ANOVA: analysis of variance
CE: constant error
CV: coefficient of variance
D: dominant
EMG: electromyographic
ER/IR: ratio of the external to internal rotators force
ER: external rotators
ET: eccentric training
GIRD: glenohumeral internal rotation deficit
GLM: general linear model
HHD: hand held dynamometer
ICC: intraclass correlation coefficient
IR: internal rotators
KPP: knee push-up plus
LT: lower trapezius
MRI: magnetic resonance imaging
MT: middle trapezius
MVC: maximum voluntary contraction
MVIC: maximum voluntary isometric contraction
ND: non-dominant
RCT: randomized clinical trial
RE: relative error
RMS: root mean square
ROM: range of motion
SA: serratus anterior
SD: standard deviation
SEM: standard error of measurment
SPADI: shoulder pain and disability index
SPP: standard push-up plus
TT: traditional rotator cuff training
US: ultrasound
UT/LT: ratio of upper to lower trapezius muscle activity
UT/MT: ratio of upper to middle trapezius muscle activity
UT/SA: ratio of upper trapezius to serratus anterior muscle activity
UT: upper trapezius
VAS: visual analogue scale