ORIGINAL ARTICLE

Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms

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Objectives: To determine if the muscle force and electromyographic activity in the scapular rotators of overhead athletes with impingement symptoms showed differences between the injured and non-injured sides.
Methods: Isokinetic peak force was evaluated during protraction and retraction of the shoulder girdle, with simultaneous recording of electromyographic activity of the three trapezius muscles and the serratus anterior muscle, in 19 overhead athletes with impingement symptoms.
Results: Paired *t* tests showed significantly lower peak force during isokinetic protraction at high velocity ($p<0.05$), a significantly lower protraction/retraction ratio ($p<0.01$), and significantly lower electromyographic activity in the lower trapezius muscle during isokinetic retraction on the injured side than on the non-injured side ($p<0.05$).
Conclusion: These results confirm that patients with impingement symptoms show abnormal muscle performance at the scapulothoracic joint.

The shoulder plays a vital role in many athletic activities. Overhead movements such as throwing, swimming, and serving in tennis repetitively place the shoulder in vulnerable positions possibly leading to impingement syndrome. This syndrome has been classified as primary or secondary. Primary impingement refers to mechanical encroachment into the subacromial space by the humeral head, often seen in middle aged patients.[1–5] The symptoms of secondary impingement syndrome are thought to be a result of shoulder instability, posterior capsule tightness, and scapulothoracic weakness, which may contribute to functional shoulder instability.[2 6 7] Functional shoulder instability has been defined as the clinical situation in which the pathology does not allow the humeral head to move excessively relative to the confines of the glenoid fossa or to pass over the rim as in a subluxation of dislocation (anatomical glenohumeral instability). However, generally lax or overstretched glenohumeral ligaments intermittently jeopardise normal shoulder function.[8] The patient feels that he/she cannot trust or control the stability of the shoulder, hence the designation "functional shoulder instability".[9] It is now thought that functional instability in the shoulder may be one of the causes leading to a vicious circle involving microtrauma and secondary impingement, and may eventually lead to chronic shoulder pain.[10]

Many muscles are attached to the scapula. Some act as scapular rotators, and others are concerned with glenohumeral movement. The major upward rotators of the scapula are the upper and lower fibres of the trapezius and the lower digitations of the serratus anterior.[2 11] Most authors[12–14] agree that weakness in one or more scapular rotators may cause muscular imbalance in the force couples around the scapula, leading to abnormal kinematics. Scapulothoracic dysfunction is often seen in patients with shoulder problems.[2 12–22] In a recent study,[22] we found that overhead athletes with impingement symptoms showed abnormally timed muscle recruitment in the trapezius muscle. The most striking finding in this study was the observation that, in response to a sudden arm movement, the patient group showed significantly slower muscle activation in the middle and lower trapezius compared with the control group, on the injured as well as the non-injured side.

A current belief is that weakness of the scapular musculature will affect normal scapular positioning. It has been suggested that excessive motion of the scapula may increase the stress on the glenohumeral capsular structures and lead to increased glenohumeral instability. Malpositioning of the scapula for any given arm configuration may also influence the instantaneous centre of shoulder rotation, which can significantly alter moments of force generation about the shoulder.[23]

Isokinetic evaluation of muscle performance is commonly used in the assessment of muscle performance in healthy and injured athletes. In particular, evaluation of isokinetic glenohumeral external and internal rotation movements is considered an appropriate tool for investigating muscle performance in injured shoulders.[24 25] However, these investigations do not reflect the quality of scapulothoracic muscle performance. Recently, an isokinetic protocol was introduced to evaluate muscle performance of shoulder girdle protractors and retractors, using the Biodex isokinetic dynamometer.[26] In addition, the use of electromyography (EMG) is considered valuable for investigating neuromuscular performance in healthy and injured shoulders.[27–29]

The aim of this study was to investigate the isokinetic muscle performance of the shoulder girdle protractors and retractors, with simultaneous recording of EMG activity in the scapular muscles in overhead athletes showing symptoms of impingement.

METHODS

Subjects

Nineteen overhead athletes (14 men, five women) with unilateral shoulder pain on the dominant side were included in this report. The mean age was 21.9 years (range 18–25). Thirteen patients were volleyball players, three were tennis players, and three were athletes from other overhead sports. All subjects completed questionnaires on their shoulder pain, training, and athletic performance.

Shoulder impingement was determined by history taking and confirmed by physical examination (Neer, Hawkins', supraspinatus, apprehension, and relocation tests). Patients were included in the impingement group if they fulfilled at least two of the following five criteria[19 22 30 31]:

- Positive Neer sign: reproduction of pain when the humerus is flexed to end of range with overpressure.
- Positive Hawkins' sign: reproduction of pain when the shoulder is passively placed in 90° forward flexion and internally rotated to end of range.
- Positive Jobe's sign: reproduction of pain and lack of force production with isometric elevation in the scapular plane in internal rotation (empty can).
- Pain with apprehension: reproduction of pain when an anteriorly directed force is applied to the proximal humerus in the position of 90° of abduction and 90° of external rotation.
- Positive relocation: reduction of pain after a positive apprehension test when a posteriorly directed force is applied to the proximal humerus in the position of 90°/90°.

For inclusion, at least one impingement sign needed to be positive, with in addition a second positive impingement test or a painful apprehension/positive relocation test.[22] It is thought that patients with minor instability and secondary impingement will experience pain, but not apprehension with these tests.[10 32] Although not agreed on in literature, these tests are currently considered to be valuable in the clinical evaluation of symptoms associated with impingement.[10 32]

Subjects were excluded if they had a history of dislocation of the shoulder, shoulder surgery, current symptoms related to the cervical spine, or documented structural injuries to the shoulder complex. All subjects gave their written informed consent to participate in the study. The study was approved by the ethics committee of Ghent University.

Testing procedure

EMG recording

Before electrode application, the skin was cleaned with alcohol to reduce impedance (typically <10 kOhm). Bipolar surface electrodes (Blue Sensor; Medicotest, Ballerup, Denmark) were placed with a 1 cm interelectrode distance over the upper, middle, and lower portions of the trapezius muscle and the lower portion of the serratus anterior, according to the instructions of Basmajian and DeLuca.[33] A reference electrode was placed over the clavicle. Each set of bipolar recording electrodes from each of four muscles was connected to a Noraxon Myosystem 2000 EMG receiver (Noraxon USA, Inc, Scottsdale, Arizona, USA). The sampling rate was 1000 Hz. All raw myoelectric signals were pre-amplified (overall gain = 1000, common rate rejection ratio 115 dB, signal to noise ratio <1 μV RMS baseline noise, filtered to produce a bandwidth of 10–1000 Hz). Measurements from the Biodex dynamometer and EMG recordings were fully synchronised through the analogue input of the EMG receiver. Both EMG signals and movement direction/isokinetic force production were stored using the Myoresearch software program.

Before isokinetic testing, EMG signal quality was verified for each muscle by having the subject perform isometric contractions in manual test positions specific to each muscle of interest.[34] Subjects performed three five second maximum voluntary isometric muscle contractions against manual resistance from the principal investigator, with a five second pause between contractions.[28 29] As a normalisation reference, EMG data were collected during maximal voluntary contraction for each muscle. After signal filtering with a low pass filter (single pass, Butterworth, 6 Hz low pass filter of the 6th order) and visual inspection for artefacts, the peak average EMG value over a window of one second was calculated for each trial. Further calculations were performed with the mean of the repeated trials as a normalisation value (100%).[22 35 36]

Isokinetic evaluation

All tests were performed using a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, New York, USA). The testing session started with a warm up procedure, consisting of shoulder movements in all directions, push up exercises against the wall, and stretching exercises for the rotator cuff and scapular muscles. The non-injured shoulder was tested first, followed by the injured shoulder.

For the testing procedure, the closed chain attachment was fixed to the isokinetic dynamometer in a horizontal position. The hand grip was inserted into the attachment receiving tube with the neutral handle facing up, in order to keep the glenohumeral joint in a neutral rotational position. The chair was rotated to 15° and the dynamometer to 45° (fig 1). Subjects were assessed in the seated position with arm horizontal in the scapular plane, which is 30° anterior to the frontal plane. Subjects were instructed to keep the elbow extended. The trunk was stabilised by a strap positioned diagonally from the contralateral shoulder across the chest. Subjects were first tested at 12.2 cm/s (angular velocity 60°/s) and then at 36.6 cm/s (angular velocity 180°/s). Range of motion was assessed by asking the subject to perform a maximal protraction and a maximal retraction movement. No correction was made for gravity because the movement was in a horizontal plane. The test started in a maximally retracted position; the subjects were then instructed to perform maximal protraction and retraction movements over the total range of motion. Five repetitions were performed at a linear velocity of 12.2 cm/s and, after a rest period of 10 seconds, 10 repetitions at a linear velocity of 36.6 cm/s. All subjects performed five familiarisation trials before data were collected, and they all received verbal encouragement. Visual feedback from the computer screen was not allowed. After the tests, the results were printed on a report consisting of peak force and total work values. In a previous study, the test-retest reproducibility of this procedure was found to be

Figure 1 Experimental set up for the isokinetic and electromyographic testing procedure.

Table 1 Peak force during isokinetic protraction and retraction movements at low (12.2 cm/s; five repetitions) and high (36.6 cm/s; 10 repetitions) velocity, and agonist/antagonist ratios

Velocity (cm/s)	Protraction			Retraction			Protraction/retraction ratio		
	Non-injured	Injured	p Value	Non-injured	Injured	p Value	Non-injured	Injured	p Value
12.2	369.2 (113.1)	346.8 (114.2)	0.14	349.0 (111.9)	361.7 (127.2)	0.53	1.08 (0.13)	0.97 (0.12)	0.01*
36.6	268.1 (91.4)	237.9 (85.6)	0.04*	296.9 (115.6)	272.0 (96.7)	0.16	0.96 (0.25)	0.88 (0.88)	0.31

Values are mean (SD) (n = 19).
*Significant difference, $p<0.05$.

good to excellent for the peak force values (intraclass correlation coefficient 0.88–0.96) and very good for total work values (intraclass correlation coefficient 0.82–0.89).[26]

EMG signal processing

All raw EMG signals were analogue/digital converted (12 bit resolution) at 1000 Hz. They were then digitally full wave rectified and low pass filtered (single pass, Butterworth, 6 Hz low pass filter of 6th order). Results were normalised to the maximum activity observed during the maximal voluntary contraction trials. After rectification, filtering, and normalisation, further analysis was performed on five periods for each movement direction at low velocity and 10 periods for each movement direction at high velocity. Periods were defined by markers, automatically placed on the EMG signal, defining a protraction or a retraction movement. The mean amplitude EMG signal, expressed as a percentage of maximal voluntary contraction, was used to assess the activity of the three parts of the trapezius muscle and the serratus anterior muscle in each movement direction, at both linear velocities.

Statistical analysis

Mean (SD) was calculated for all dependent variables—isokinetic peak force for protraction and retraction, and EMG activity of upper trapezius, middle trapezius, lower trapezius, and serratus anterior—expressed as percentage of maximal voluntary contraction during isokinetic protraction and retraction, at both low and high velocity. In addition, the agonist/antagonist muscle ratio was calculated for both sides, with the protraction force as the agonist value and the retraction force as the antagonist value.

As all data were normally distributed with equal variances, parametric tests were used for statistical analysis. Differences in isokinetic peak force and scapular rotator EMG activity between the injured and non-injured side were analysed with paired *t* tests. The α level was set at 0.05. All statistical analysis was performed with the Statistical Package for Social Sciences (SPSS), version 10.0.

RESULTS

The results of the descriptive statistical analyses are summarised in table 1 for the isokinetic peak force values and agonist/antagonist ratios at both speeds for both sides, in table 2 for the EMG activity of the three trapezius muscles and serratus anterior muscle during isokinetic protraction at both speeds for both sides, and in table 3 for the EMG activity of the same muscles during isokinetic retraction.

The statistical analysis with paired *t* tests revealed significantly lower isokinetic protraction peak force on the injured side at high velocity ($p<0.05$) compared with the non-injured side, a significantly lower protraction/retraction ratio at low velocity for the injured shoulder ($p<0.01$), and significantly less EMG activity in the lower trapezius during isokinetic retraction at high velocity on the injured side ($p<0.05$).

DISCUSSION

The purpose of this retrospective study was to investigate two aspects of motor control about the shoulder girdle, namely isokinetic protraction and retraction force production and associated muscle activity in the scapular muscles, and to identify any deficits in these parameters in overhead athletes with shoulder impingement symptoms, compared with their contralateral non-injured side.

In our investigation, peak force values for isokinetic protraction ranged from 237.9 to 369.2 N, depending on the movement velocity and the side tested. These values are slightly higher than those obtained in a previous study on normal subjects.[26] However, in the previous study, normal, non-athletic subjects were evaluated in order to establish day to day repeatability of the procedure. The higher values obtained in this study probably reflect overall enhanced muscle performance in overhead athletes compared with non-athletic subjects. However, it is striking that, in contrast with the study on healthy subjects, in whom no significant differences were found between the dominant and non-dominant sides, the injured shoulders in this study showed significantly lower protraction peak force at high velocity. As, to our knowledge, isokinetic performance of the shoulder girdle muscle has not been investigated in patients with shoulder problems, we have no experimental data with which to compare our results. However, several authors have emphasised the importance of scapula protraction during throwing movements.[14 17] During the acceleration phase in

Table 2 Electromyographic activity of upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA), expressed as percentage of maximal voluntary contraction (MVC), during isokinetic protraction movements at low (12.2 cm/s; five repetitions) and high (36.6 cm/s; 10 repetitions) velocity

Velocity (cm/s)	UT (% MVC)			MT (% MVC)			LT (% MVC)			SA (% MVC)		
	Non-injured	Injured	p Value	Non-injured	Injured	p Value	Non-injured	Injured	p Value	Non-injured	Injured	p Value
12.2	12.9 (8.5)	13.4 (7.3)	0.81	12.8 (6.6)	15.9 (12.2)	0.17	4.4 (1.6)	5.4 (3.1)	0.12	41.3 (16.4)	42.8 (17.9)	0.65
36.6	12.0 (7.2)	11.8 (6.1)	0.92	12.4 (6.4)	14.6 (7.8)	0.15	6.7 (4.3)	6.6 (4.1)	0.94	36.6 (12.5)	39.3 (17.5)	0.43

Values are mean (SD) (n = 19).

Table 3 Electromyographic activity of upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA), expressed as percentage of maximal voluntary contraction (MVC), during isokinetic retraction movements at low (12.2 cm/s; five repetitions) and high (36.6 cm/s; 10 repetitions) velocity

Velocity (cm/s)	UT (% MVC)			MT (% MVC)			LT (% MVC)			SA (% MVC)		
	Non-injured	Injured	p Value	Non-injured	Injured	p Value	Non-injured	Injured	p Value	Non-injured	Injured	p Value
12.2	37.3 (17.8)	36.3 (13.3)	0.83	23.7 (16.1)	19.5 (11.3)	0.27	13.3 (7.3)	13.0 (8.7)	0.89	10.9 (12.7)	11.3 (11.3)	0.88
36.6	45.0 (16.1)	43.2 (9.8)	0.62	25.5 (16.7)	19.9 (10.2)	0.23	17.8 (12.9)	11.7 (4.76)	0.04*	14.7 (12.6)	18.7 (18.8)	0.37

Values are mean (SD) (n = 19).
*Significant difference, $p<0.05$.

particular, the serratus anterior concentrically protracts the scapula as the arm is adducted and internally rotated.[2 37] As acceleration proceeds, the scapula must protract smoothly, first laterally and then anteriorly around the thoracic wall to allow it to maintain a normal position in relation to the humerus, thus improving dynamic glenohumeral stability.[14] A decreased protraction force may compromise this functional shoulder stability and lead to tensile overload in the glenohumeral joint. In addition, it has been suggested that the scapulothoracic muscles may be inhibited by painful conditions around the shoulder. It appears that the serratus anterior muscle and the lower trapezius muscle are the most susceptible to the effect of inhibition.[3 12 14 20] Our results confirm this. The observation that differences in force output for the protraction movement are only found in the testing condition at high velocity deserves special attention. It seems that the serratus anterior lacks power rather than absolute muscle strength. Indeed, the lower speeds (30–120°/s) have been defined as those of strength, while the higher speeds (120–300°/s) have been defined as power.[38] This may have some clinical implications in the determination of treatment goals in overhead athletes with impingement symptoms.

We found a significantly lower agonist/antagonist ratio on the injured side (0.97) than on the non-injured side (1.05). In a previous study on healthy, non-athletic subjects, protraction/retraction ratios were found to be 1.11 and 1.18 for the dominant and non-dominant side respectively at low velocity. These values are slightly higher than the ratios found in this investigation. However, the population studied in the previous investigation consisted of healthy non-athletic subjects, whereas our population was involved in overhead sports. Wilk *et al*[39] documented the isometric scapular muscle strength values of professional baseball players. They ranged from 1.02 to 1.24. In addition, the players exhibited a lower protraction/retraction ratio on the dominant side than on the non-dominant side. We found slightly lower protraction/retraction ratios than Wilk *et al*,[39] but the results agree with respect to the side differences. However, Wilk *et al*[39] investigated professional baseball players without shoulder problems. Moreover, we examined isokinetic muscle strength, whereas isometric muscle performance was evaluated by Wilk and coworkers.[39] Comparisons between the two studies should be interpreted with caution.

Analysis of EMG muscle activity in the scapular muscles during isokinetic movements showed a significant decrease in activity in the lower trapezius muscle during retraction on the injured side compared with the non-injured side. This finding may reflect a muscular imbalance among the three regions of the trapezius, as these side differences were not found in the upper and middle trapezius, and there were no side differences in the force output. A similar muscle imbalance in the trapezius muscle, with a temporal delay in muscle activity in the lower trapezius, has previously been shown in overhead athletes with impingement symptoms.[22]

The significant side differences may reflect muscle imbalance in the scapular force couple. As alteration in dominance of any muscle can compromise the muscle balance around the scapula, this may indicate an abnormality in the coordinated rotation of the scapula on the thorax (scapulohumeral rhythm). For example, elevation of the acromion is imprecise without the guidance and control of the lower trapezius and rhomboidei.[2 14 40]

Although the results of this study may be considered clinically relevant, several aspects of normal scapular function were not examined. The testing position (the subject sits with arm elevated horizontal in the scapular plane) lacks functional relevance, as gravity is eliminated and force dependent muscle activation patterns of the trunk are not facilitated. In addition, only concentric force values were obtained. However, eccentric force output and EMG activity are relevant muscle performance variables, especially in the overhead throwing motion.[14 32] The lower trapezius muscle in particular is important for its eccentric role in shoulder protraction.[17 39] Future research directions should emphasise these functional muscle performance parameters.

This study highlighted isokinetic muscle force and muscle activity associated with protraction and retraction movements in the scapular plane in patients suffering from shoulder impingement. Further research is necessary to evaluate these parameters in overhead athletes without impingement symptoms to create a reference base for clinical evaluation and rehabilitation of scapular function in patients with shoulder pain.

Conclusions

We compared the isokinetic force of the shoulder girdle muscle and associated EMG activity in the scapular muscles of the painful and non-injured shoulders in overhead athletes with impingement symptoms on their dominant side. There were significant side differences with respect to protraction muscle force, suggesting weakness in the serratus anterior muscle and decreased EMG activity in the lower trapezius muscle during isokinetic retraction, indicating muscle imbalance in the stabilising force couple around the scapula. However, these results should be extrapolated to the clinical situation in overhead athletes with caution, and future investigations should emphasise eccentric scapular muscle activation patterns in functional throwing positions.

These findings support the hypothesis that shoulder impingement may be related to scapulothoracic dysfunction and may indicate conservative treatment of impingement syndrome.

Take home message

Overhead athletes with impingement symptoms show a decrease in force in the serratus anterior muscle and an imbalance in the lower trapezius muscle. This may indicate conservative treatment of shoulder impingement.

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