

The Effect of Scapular-Retractor Fatigue on External and Internal Rotation in Patients With Internal Impingement

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Context: Scapular strengthening is thought to be an important component of the rehabilitation of patients with internal impingement. **Objective:** To determine the effect of scapular-retractor-muscle fatigue on internal- and external-rotation-torque production in patients with internal impingement. **Design:** Case control study. **Setting:** Outpatient clinic. **Participants:** 15 patients and 18 healthy subjects. **Intervention:** A scapular-retractor-fatigue protocol. **Main Outcome Measure:** Shoulder-rotation-torque production. **Results:** After the scapular-retractor-fatigue protocol external-rotation strength was reduced in patients (involved 25%, noninvolved 19%; $P < .001$). **Conclusion:** Fatigue in the scapular retractors resulted in lower shoulder-rotation-torque production. These findings emphasize the importance of the scapular retractors for proper function of the shoulder rotators with the arm in an abducted position in patients with internal impingement. **Keywords:** shoulder, strength, stability

Scapular-strengthening exercises are regarded as an integral part of rehabilitation for patients with internal impingement. The importance of scapular stabilization to establish a proximal base of support for the glenohumeral joint has been investigated extensively.¹⁻¹² Studies have linked scapular-muscle dysfunction to anterior instability, multidirectional instability, and impingement.^{6-9,13-17} Kibler⁷ emphasizes the use of rehabilitation exercises to improve scapular stability in patients with glenohumeral instability to decrease anterior subluxation and subsequent impingement. Specifically, in throwing athletes scapular dysfunction has been associated with internal impingement and SLAP tears.^{7,13,14,18}

The role of the scapular stabilizers in the pathological shoulder is vital in evaluating and treating shoulder dysfunction.¹⁷ Kibler⁷ suggests that when there is a lack of a stable muscle anchor, it affects all the functions of the muscles attached to the scapula. The scapular retractors stabilize the scapula to provide a solid fulcrum for dynamic glenohumeral rotation. Fatigue in the scapular retractors might decrease force production of the rotator-cuff muscles and contribute to glenohumeral internal impingement.^{19,20} The relationship between fatigue of the

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scapular stabilizers and glenohumeral external- and internal-rotation-torque production has not been examined previously. Therefore, the purpose of this study was to determine the effect of scapular-retractor-muscle fatigue on external- and internal-rotation-torque production in patients with internal impingement compared with controls.

Methods

Sample

Thirty-three subjects (7 men and 8 women with internal impingement, age 25 ± 9.7 years, height 169 ± 12 cm, weight 67 ± 18.6 kg, and 12 men and 6 women without pathology, age 20 ± 3.4 , height 171 ± 9.6 cm, weight 72 ± 16.8 kg) were recruited to participate in the study. Inclusion criteria for the healthy subjects consisted of no history of shoulder, arm, or upper trunk surgery and no medically diagnosed shoulder pathology for at least 1 year. The diagnosis of pathologic internal impingement in the patient group was made by an orthopedic surgeon experienced in treating shoulder injuries. A complete history and physical examination were coupled with an X-ray and MRI results for diagnosis. The special tests performed by the orthopedic surgeon included an apprehension/relocation test, the active compression test of O'Brien et al.,²¹ anterior-posterior drawer test, sulcus test for inferior instability, testing of range of motion, manual muscle testing of shoulder-girdle strength, and visual appreciation of scapular kinesics.²² Inclusion criteria for the pathological subjects consisted of subjective clicking in the shoulder on active movement, positive active compression test, positive relocation test, and presence of an internal impingement on MRI. Patients were excluded if additional pathology was seen on MRI. Nine of the 15 patients had subtle anterior instability with no frank instability. All subjects gave informed consent, and the procedures were approved by an institutional review board.

Procedures

Isokinetic internal- and external-rotation strength and scapular-retraction strength were measured in patients before and after a scapular-retractor-fatigue protocol. The healthy subjects underwent 2 different test sessions. One session was exactly the same as that performed by the patients (internal- and external-rotation strength and scapular-retraction strength assessed before and after scapular-retractor fatigue). In the second session, internal- and external-rotation strength were measured before and after a 15-minute rest period. The 15-minute rest period represented the duration of the scapular-retractor-fatigue protocol. The order of the fatigue and control sessions was alternated between subjects, with the second session performed 2 weeks after the first. The purpose of this control session was to determine whether the initial isokinetic internal- and external-rotation-strength test affected testing repeated after 15 minutes. This was to ensure that any change in internal- and external-rotation strength after the scapular-retractor-fatigue protocol was not the result of fatigue of the shoulder rotators secondary to the initial strength test.

Shoulder-Rotation-Strength Testing

Isokinetic internal- and external-rotation strength were measured bilaterally (Biodex System 3, Shirley, NY) at 90°/s. Order of testing was alternated between involved and noninvolved arms for patients and between dominant and nondominant arms for healthy subjects. This order was repeated for testing after the scapular-retractor-fatigue protocol or the 15-minute rest period. A 2-minute warm-up was performed on an upper body ergometer. For isokinetic strength testing subjects were seated with the test arm in 90° of shoulder abduction and 90° of elbow flexion. The participant's trunk was secured using a bilateral seat belt to minimize accessory muscle use during the test. Five maximum pain-free contractions were performed in each direction, and the peak torque was recorded. None of the subjects experienced pain during testing.

Scapular-Retractor-Strength Testing

Bilateral scapular-retraction strength was tested using a handheld dynamometer (Lafayette Instruments, IN; Figure 1). Subjects were in the prone position with the elbow extended and the glenohumeral joint in 90° of horizontal abduction according to the manual-muscle-testing protocol for the scapular retractors described by Daniels and Worthingham.²³ The average of 3 test trials for each shoulder was recorded.



Figure 1 — Position for scapular-retractor-strength testing using a handheld dynamometer.

Scapular-Retractor-Fatigue Protocol

After scapular-retraction-strength measurements, participants were instructed on how to perform a seated rowing exercise to fatigue the scapular retractors using a standard-design cable column with weight stack for isotonic weight training. They were seated in a chair without arms and instructed to sit with their back flush against the chair back during the entire exercise, with both legs flexed and feet on the floor (Figure 2). The resistance was set at 40% of subjects' body weight, and subjects performed the exercise to "failure" as determined by the tester according to the following criteria: (1) inability to retract the scapula completely before rowing on 3 consecutive repetitions, (2) inability to maintain seated posture against the seat back for 3 consecutive repetitions, or (3) inability to break the frontal plane at the midaxial region with the elbows on 3 consecutive repetitions while maintaining proper exercise technique. The tester used tactile and verbal cues to ensure complete scapular retraction on each repetition. When the point of failure was reached subjects were again tested for scapular-retraction strength. Isokinetic internal- and external-rotation-strength testing was repeated within 3 to 5 minutes of the postexercise scapular-retraction-strength test.



Figure 2 — The tester uses tactile and verbal cues for complete scapular retraction on each repetition during the scapular-retractor-fatigue protocol.

Assessment of Muscle Activation During Glenohumeral Rotation and Scapular Retraction

Because the aim of the study was to determine whether scapular-retractor fatigue affected glenohumeral internal- and external-rotation strength it was important to determine how much the internal and external rotators were activated during scapular retraction. Therefore, EMG activity was recorded from the primary internal rotator (pectoralis major), primary external rotator (infraspinatus), and primary scapular retractor (middle trapezius) during isokinetic internal and external rotation and during the rowing exercise in 8 healthy male subjects. Surface electrodes were placed bilaterally over the middle trapezius and pectoralis major, and fine-wire electrodes were placed in the infraspinatus. EMG signals were recorded during maximal internal and external rotation (3 repetitions each) and during submaximal scapular retraction (20 repetitions of seated rowing at 50% of 1-repetition maximum). For the middle trapezius, surface electrodes (Ag/AgCl; 1-cm diameter, 2-cm interelectrode distance) were placed bilaterally midway between the inferior angle of the scapula and the horizontally adjacent spinous process. For the pectoralis major, surface electrodes were placed bilaterally 4 cm medial to the deltopectoral crease along the presumed line of the pectoralis major muscle fibers. For the infraspinatus, bipolar fine-wire electrodes were placed 2 cm inferior to the center of the scapular spine. EMG signals were filtered (10 to 500 Hz) and amplified (60 dB; Noraxon TeleMyo) before sampling at 1 kHz (BioPac Systems Acq-Knowledge) and then rectified and smoothed (100-millisecond RMS). Peak EMG (1-second average) was normalized to activity recorded during maximum voluntary effort for standardized manual tests for the respective muscles.

Data Analysis

Changes in internal- and external-rotation strength and scapular-retraction strength after the scapular-retractor-fatigue protocol are expressed as a percentage of pre-exercise values ($\{[post - pre]/pre\} \times 100$). Changes significantly greater than zero by 1-sample *t* test were deemed significant strength loss. For the patient group, differences in percent strength loss between the internal and external rotators and between the involved and noninvolved sides after the scapular-retraction-fatigue protocol were assessed using side-by-muscle-group repeated-measures analysis of variance. For the healthy subjects, differences in percent strength loss between the fatigue trial and control trial, between the internal and external rotators, and between the dominant and nondominant arms were assessed using trial-by-muscle-group-by-side repeated-measures analysis of variance. Between-groups differences in strength loss after the scapular-retractor-fatigue trials were assessed using group- (patient vs healthy) by-side- (involved/dominant vs noninvolved/nondominant) by-muscle-group (internal vs external rotation) mixed-model analysis of variance. One-sample *t* tests were also used to confirm scapular-retractor-strength loss after the scapular-retractor-fatigue protocol. Differences in absolute strength or scapular-retractor-fatigue effects were not compared between patients and healthy subjects because the groups were not matched. The healthy subjects served to confirm that any observed change in internal- and external-rotation strength after the scapular-retractor-fatigue protocol was not a result of

the prior isokinetic internal- and external-rotation-strength test. Means \pm SEs are reported in text and graphs.

Results

Patient Group

For patients with internal impingement the scapular-retractor-fatigue protocol resulted in $17\% \pm 9\%$ scapular-retraction-strength loss on the involved side ($P < .0001$) and $16\% \pm 12\%$ on the noninvolved side ($P < .0001$). After the scapular-retractor-fatigue protocol the patients showed an overall strength loss of $17.9\% \pm 3.2\%$ (combined across side and muscle group). Strength loss was significantly greater on the involved than the noninvolved side ($22.5\% \pm 3.2\%$ vs $13.3\% \pm 4.2\%$, $P < .05$; Figure 3). Strength loss was also significantly greater in external rotation than internal rotation ($21.9\% \pm 2.7\%$ vs $13.9\% \pm 4.3\%$, $P < .05$; Figure 3). The side-by-muscle-group interaction was not significant ($P = .51$).

Baseline internal- and external-rotation strength were not different between the involved and noninvolved sides in patients (external rotation $P = .15$, internal rotation $P = .10$).

Healthy Subjects

For healthy subjects the scapular-retractor-fatigue protocol resulted in $10\% \pm 12\%$ scapular-retraction-strength loss on the dominant side ($P < .01$) and $21\% \pm 9\%$ on the nondominant side ($P < .0001$). Fatigue in the scapular retractors was significantly less on the dominant side ($P < .01$). Strength loss was significantly greater after the fatigue trial than after the control trial ($15.7\% \pm 3.1\%$ vs $-1.0\% \pm 4.2\%$, $P < .05$; Figure 4). There were no significant interactions for trial by side ($P = .38$), trial by muscle group ($P = .74$), or trial by side by muscle group ($P = .51$).

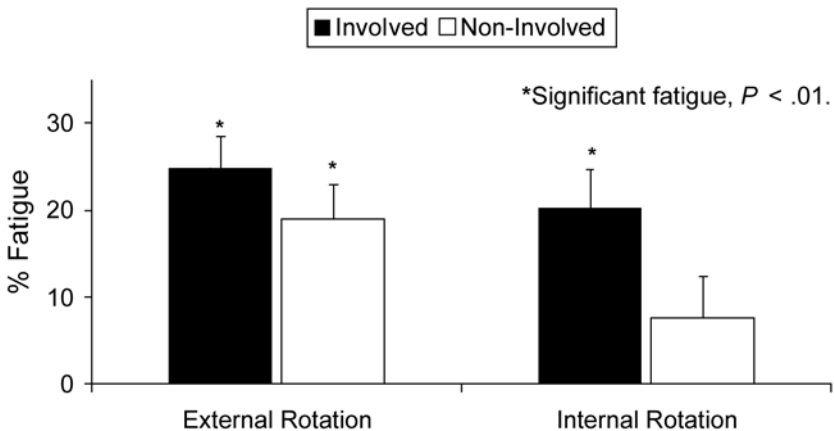


Figure 3 — Fatigue effects (percent change) for external- and internal-rotation strength of the involved arm and noninvolved arm in patients with internal impingement.

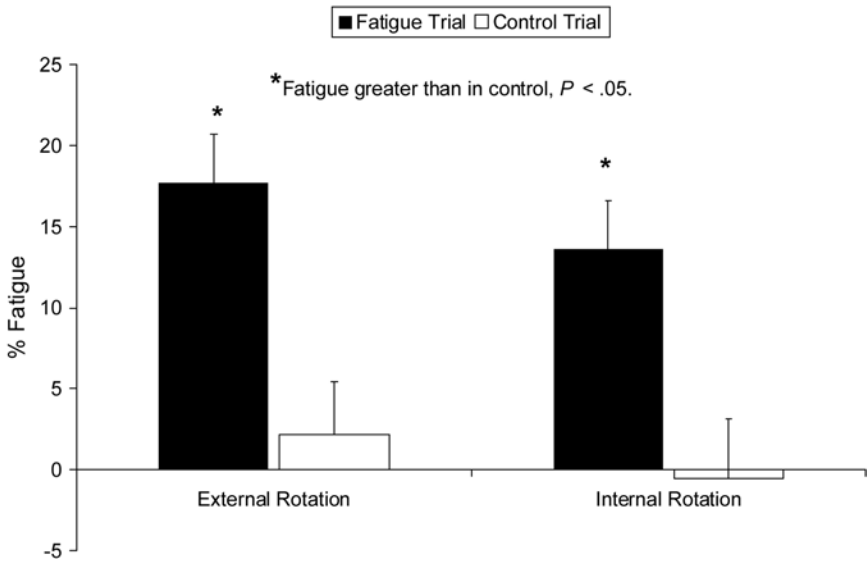


Figure 4 — Fatigue effects (percent change) in the healthy subjects after the fatigue protocol and control trial.

Therefore, subsequent analyses were examined for the fatigue trial only. Strength loss after the scapular-retraction-fatigue trial was not different between external and internal rotation ($17.7\% \pm 3.3\%$ vs $13.6\% \pm 3.7\%$, $P = .24$) or between the dominant and nondominant sides ($16.9\% \pm 3.0\%$ vs $14.5\% \pm 4.0\%$, $P = .49$). The side-by-muscle-group interaction was not significant ($P = .63$).

Baseline internal-rotation strength was significantly greater on the dominant side (8% higher $P < .05$), with no difference in external-rotation strength ($P = .38$).

For between-groups comparisons the 3-way group- (patients vs healthy subjects) by-side- (involved/dominant vs noninvolved/nondominant) by-muscle-group (internal vs external rotation) interaction was not significant ($P = .81$) and the group-by-muscle-group and group-by-side interactions were not significant ($P = .42$ and $P = .19$, respectively).

EMG Findings

Middle trapezius activity was similar during submaximal rowing (76% maximum voluntary contraction [MVC]) and maximal internal rotation (80% MVC; $P = .73$). By contrast, pectoralis major activity was minimal during submaximal rowing (14% MVC). Pectoralis major activity during submaximal rowing (14% MVC) was significantly lower ($P < .0001$) than middle trapezius activity during both submaximal rowing (76% MVC) and maximal internal rotation (80% MVC). Middle trapezius activity was actually higher ($P < .05$) during maximal external rotation (142% MVC) than during submaximal rowing (76% MVC). Infraspinatus activity during submaximal rowing (79% MVC) was similar to middle trapezius activity

during submaximal rowing (76%; $P = .87$) but tended to be lower than infraspinatus activity during maximal internal rotation (142%; $P = .08$).

Discussion

The role of the rotator-cuff muscles in stabilizing the humeral head in the glenoid fossa is well documented.^{5,8,16,23,24} Given the focus on strengthening and neuromuscular control of scapular-stabilizer muscles in shoulder rehabilitation, we hypothesized that fatigue in the scapular retractors would compromise force generation of the rotator-cuff muscles. Specifically, the rationale was that the scapula's ability to provide a stable base of support for the rotator cuff to produce torque would be diminished. The scapular-retractor-fatigue protocol resulted in a significant strength loss in scapular retraction and a subsequent marked loss of external- and internal-rotation-torque production.

Chen et al²⁵ used radiographic evaluation to study the effect of rotator-cuff-muscle fatigue on glenohumeral kinematics. Glenohumeral anteroposterior radiographs were taken at 45° intervals as the arm was abducted in the plane of the scapula from 0° to 135°. This series of radiographs was taken before and immediately after the subject performed a series of deltoid- and rotator-cuff-fatiguing exercises. After fatigue, excursion of the humeral head increased by an average of 2.5 mm between the tested positions. With the initiation of abduction, the humeral head demonstrated significant superior migration or translation in all positions tested. This study demonstrates the importance of rehabilitation to maximize the endurance and strength of the rotator-cuff muscles. Unfortunately, the scapular muscles were not included in the fatiguing trials. Cools et al⁴ did study the scapular rotators of overhead athletes with impingement symptoms to determine whether there were differences between the injured and noninjured sides. Isokinetic peak force was evaluated during protraction and retraction of the shoulder girdle in 19 overhead athletes with impingement symptoms. The results demonstrated a significantly lower peak force during isokinetic protraction on the involved side, a significantly lower protraction:retraction ratio on the involved side, and significantly lower electromyographic activity in the lower trapezius muscle during isokinetic retraction on the involved side. These results confirmed that patients with impingement symptoms show abnormal muscle performance at the scapulothoracic joint.

Kibler⁷ was one of the first authors to link a lack of scapular stability to glenohumeral instability and suggested that when the scapular stabilizers fatigue, the glenoid fossa is not positioned properly and harmful stress might be placed on the anterior capsule of the glenohumeral joint, resulting in instability. The effect of scapular-retractor fatigue on external- and internal-rotation-torque production demonstrated in this study lends support to this concept. Recently, von Eisenhart-Rothe et al¹⁹ examined the relationship of scapular positioning with humeral head centering in patients with atraumatic shoulder instability. A strong correlation between altered scapular position and increased translation of the humeral head in the direction of the instability was demonstrated. Ozaki²⁴ investigated glenohumeral movements in the scapular plane in patients with inferior and multidirectional instabilities using cineradiography and found decreased upward rotation

of the glenoid fossa in these patients compared with patients with healthy shoulders but did not identify the role of the rotator cuff.

A limitation of this study is that activation of the internal and external rotators during the rowing exercise might have contributed to the observed decreases in external- and internal-rotation strength. Therefore, EMG activity of selected internal rotators (pectoralis major), external rotators (infraspinatus), and scapular retractors (middle trapezius) was recorded during submaximal rowing and maximal internal and external rotation. It was apparent that the pectoralis major was minimally active during the rowing exercise (14% MVC) and the scapular retractors were highly active (80% MVC) during maximal internal rotation. Therefore, the 14% strength loss in internal rotation after the rowing exercise (average for all subjects) can be attributed to scapular-retractor fatigue rather than fatigue of the internal rotators. In contrast, the external rotators were highly active during the rowing exercise (78% MVC). In addition, the middle trapezius was maximally active (141% MVC) during maximal external rotation. Therefore, the 20% strength loss in external rotation after the rowing exercise (averaged for all subjects) can be attributed to fatigue in the external rotators and scapular retractors. The high activity in the infraspinatus during rowing is in contrast to the findings of Townsend et al,²⁶ who demonstrated that the supraspinatus, infraspinatus, teres minor, and subscapularis were minimally involved in the rowing exercise. This discrepancy might be attributed to differences in hand position. Townsend et al²⁶ had subjects perform the rowing motion in neutral forearm rotation, whereas in the current study the forearm was maximally supinated, which results in significant glenohumeral external rotation with scapular retraction. Future work should examine whether the infraspinatus can be deactivated during the rowing motion by reversing the grip to forearm pronation.

The activation of the middle trapezius during submaximal rowing (76% MVC) in the current study is in agreement with Mosely et al,¹¹ who demonstrated that during the rowing movement, with relatively low loads, middle trapezius activity was 59% of MVC, lower trapezius activity was 67% of MVC, and rhomboid activity was 56% of MVC (activity in the internal and external rotators was not recorded). Future studies should expand on the limited EMG work performed here by examining additional muscles involved in internal and external rotation to determine their role during scapular retraction.

The magnitude of the loss of internal- and external-rotation strength after scapular-retractor fatigue in the healthy subjects (14% and 18%, respectively) is surprising when compared with the loss of internal- and external-rotation strength that occurs with repeated maximal internal- and external-rotation contractions. A recent study on normal subjects, using the same isokinetic test setup as in the current study, demonstrated a 12% loss of internal-rotation torque and a 10% loss of external-rotation torque after 32 maximal isokinetic concentric contractions.²⁷

Conclusion

Exercise-induced fatigue of the scapular-retractor muscles resulted in decreased torque production in external and internal shoulder rotation in both the impingement group and the control group. These findings emphasize the importance of

the scapular retractors for proper function of the shoulder rotators with the arm in an abducted position.

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