Relative contributions of the infraspinatus and deltoid during external rotation in patients with symptomatic subacromial impingement

Elizabeth F. Clisby, MBBS,[a] Natalie L. Bitter, BPhysio (Hons),[b] Michael J. Sandow, BMBS, FRACS,[c,d] Mark A. Jones, MAppSc,[b] Mary E. Magarey, PhD,[b] and Shapour Jaberzadeh, PhD,[e] *Adelaide, Australia*

A principal cause of subacromial impingement (SAI) is failure of the rotator cuff to center the humeral head in the glenoid during shoulder motion, counteracting the effect of the deltoid. As rehabilitation of the rotator cuff endeavors to restore balance between these muscle groups, the purpose of this companion study was to evaluate, in the symptomatic shoulders of patients with SAI, (1) the conditions of resisted isometric external rotation (ER) that optimized the contribution of the infraspinatus and (2) the load of ER at which adduction was most effective at reducing the deltoid contribution and then to compare this with the relative contribution of the infraspinatus and the posterior and middle deltoid in asymptomatic shoulders. In 14 subjects (18 shoulders) with SAI, surface electromyographic activity of the infraspinatus and the posterior and middle deltoid and pectoralis major was recorded at low, medium, and high loads of resisted isometric ER, with and without adduction. These data were normalized to find each muscle's relative contribution to the task and were compared with normalized data from subjects with healthy shoulders. In subjects with SAI, low loads of isometric ER (10%-40% maximum voluntary isometric contraction) optimized the relative contribution of the infraspinatus. Adduction with isometric ER at 10% maximum voluntary isometric contraction reduced the middle deltoid involvement. Higher loads preferentially activated the middle deltoid over the infraspinatus and may have effected unwanted humeral head superior translation, counteracting the presumed benefits of rotator cuff ER exercises. An individualized loading regimen and the use of surface electromyography may have significant implications during rotator cuff rehabilitation. (J Shoulder Elbow Surg 2008;17:87S-92S.)

Subacromial impingement (SAI) is a common cause of shoulder pain.[3,18] Typical clinical findings include weakness,[13] decreased range of movement,[3] and crepitus[15] of the affected shoulder. Optimal rotator cuff function requires strong, healthy muscles, tendons, and bony attachments, normal capsular laxity, an even curve of the coracoacromial arch, a thin synovial bursa, and coordinated co-contraction of the cuff muscles acting in force couples.[5,15,20,21] Disruption of this complex mechanism predisposes the shoulder to a cycle of movement impairment and tissue pathology, leading to anterosuperior migration of the humeral head and subsequent impingement of the subacromial structures under the coracoacromial arch.[15,16,18,20]

A targeted exercise program, supervised by a physiotherapist, is generally considered as a first-line treatment for patients with SAI. The goal of rotator cuff rehabilitation is to redress the imbalance between the deltoid, which elevates the humerus, and the rotator cuff, which stabilizes and centers the humeral head in the glenoid.[8,10,17] Commonly, part of a conservative rotator cuff rehabilitation program includes sets of shoulder external rotation (ER) exercises, performed while maintaining adduction, to improve the strength and stabilization effect of the infraspinatus.[8,10,17] The addition of adduction to the ER exercises is thought to minimize the tendency to recruit the deltoid and abduct the shoulder, thus limiting unwanted superior migration of the humeral head, and is intended to isolate the infraspinatus from the deltoid, although the validity of this hypothesis has been questioned recently.[19]

From the [a]Medical Division, Wakefield Sports Clinic; [b]School of Health Sciences, University of South Australia; [c]Wakefield Orthopaedic Clinic; and [d]Department of Orthopaedics and Trauma, University of Adelaide; and [e]Discipline of Physiology & Research Centre for Human Movement Control, School of Molecular and Biomedical Science, University of Adelaide. Dr Jaberzadeh is currently affiliated with the School of Primary Health Care, Faculty of Medicine, Nursing and Health Sciences, Monash University, Victoria, Australia.

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Reprint requests: Elizabeth F. Clisby, MBBS, Wakefield Sports Clinic, 270 Wakefield St, Adelaide SA 5000, Australia (E-mail: *eclisby@healthon-net.com*).

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The purpose of this study was to determine the conditions of resisted isometric ER that optimize the contribution of the infraspinatus and the load of ER at which the adduction strategy is most effective at reducing the posterior and middle deltoid contributions in subjects with SAI. The third aim was to determine whether there were any differences in relative muscle activation of the infraspinatus and the posterior deltoid and middle deltoid when compared with asymptomatic shoulders. The relative contributions of these muscles were investigated under low, medium, and high loads of resisted isometric ER, with and without the addition of adduction, in subjects with SAI and were compared with healthy shoulders in a group of asymptomatic subjects, assessed with the same experimental protocol.

MATERIALS AND METHODS

Fifteen subjects with a clinical diagnosis of SAI were invited to participate in the study. Inclusion criteria were as follows: aged 18 years or over, pain over the anterior and lateral aspects of the affected shoulder, pain with active shoulder elevation, pain on resisted elevation of the affected arm at 90° in the plane of the scapula, and a positive Hawkins test.[14] Exclusion criteria were as follows: previous shoulder surgery on the affected side, osteoarthrosis (OA) of the glenohumeral joint or acromioclavicular joint, a suspected or confirmed full-thickness rotator cuff tear, os acromiale, adhesive capsulitis, a history of shoulder dislocation (either anterior or posterior), a suspected superior labrum anterior-posterior lesion, cervical spine problems, neurologic loss in the upper limbs, or any systemic inflammatory condition. Plain radiographs of the shoulder (true anteroposterior view, anteroposterior view in ER, and axial and outlet views) were taken to exclude glenohumeral joint OA and acromioclavicular OA and to assess the shape of the acromion. Subjects gave written consent to participate in the study, and ethical approval was obtained from the University of South Australia's Human Research Ethics Committee (Adelaide, Australia).

Demographic data (age, height, weight, and handedness) were collected. Surface electromyographic (sEMG) activity from the infraspinatus, posterior deltoid, middle deltoid, and pectoralis major was recorded from the affected shoulder by use of the protocol described by Bitter et al.[2] All subjects participated in a single testing session. The electrodes were placed as shown in Figure 1,[4] and the study protocol assessed muscle contribution during ER at 10%, 40%, and 70% of the subject's ER maximum voluntary isometric contraction (MVIC), with and without shoulder adduction.

The average root-mean-square (RMS) over the middle 5 seconds for each muscle at the different contraction levels was used as the reference value to normalize the data. Normalization of sEMG data expressed each muscle's activity during each contraction as a percentage, relative to the average of all muscles' mean RMS, essentially indicating each muscle's relative contribution to the task. For each test contraction, each muscle's relative contribution was found by expressing its mean RMS as a fraction of the reference value, which was the average of all 4 muscles' mean RMS during that contraction.[4]

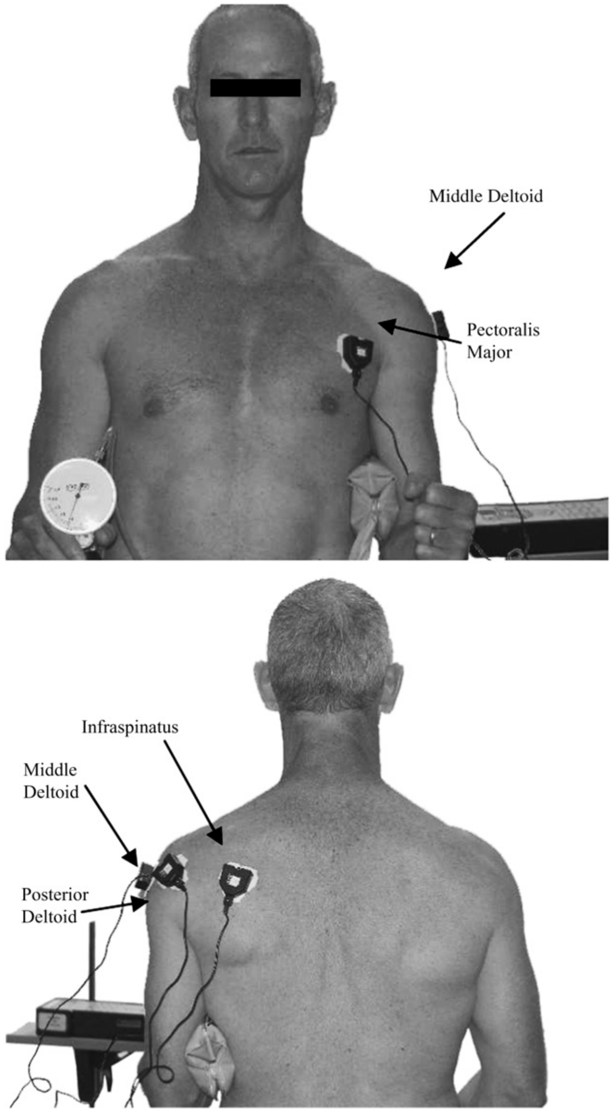

Figure 1 Surface electrode setup during experiment: anterior (*top*) and posterior (*bottom*).

The normalized sEMG data from the SAI shoulders were compared with the normalized data from the asymptomatic right shoulders collected concurrently and analyzed in a separate study applying an identical experimental protocol,[2] using a mixed model analysis,[6,22] by use of SPSS software (version 13; SPSS, Chicago, IL). Type III tests of fixed effects were conducted on each muscle to investigate whether differences existed between groups, loads, and tasks. Significant differences were further investigated via post hoc pairwise comparisons ($P < .05$).

RESULTS

Fifteen subjects were recruited, but there was an error in data recording from one, who was subsequently excluded. Of the remaining 14 subjects, 4 had

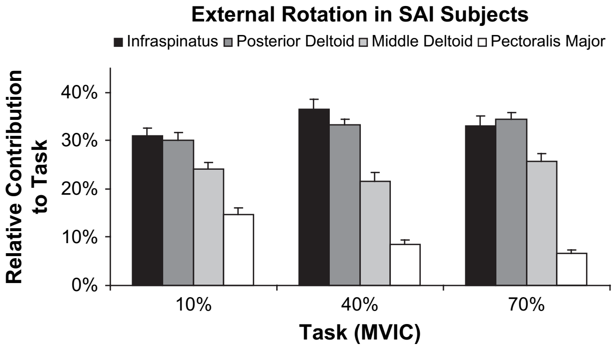

Figure 2 Relative contributions of muscles during experimental tasks (mean + SEM): ER in SAI subjects.

bilateral SAI, and thus data from 18 SAI shoulders were analyzed and compared with data taken concurrently and analyzed separately from 18 asymptomatic right shoulders.[2] Right shoulders were chosen to ensure even numbered groups, and the right shoulder was affected in most of the subjects in the SAI group.

The SAI group consisted of 5 men and 9 women, and all were right-handed but one. The mean (± SD) demographic data were as follows: age, 51.07 ± 11.06 years; height, 168.32 ± 10.78 cm; and weight, 78.64 ± 24.19 kg. Comparison with the asymptomatic group (18 healthy right shoulders) showed a similar gender ratio and similar height, but the SAI patients were slightly older (mean age in asymptomatic group, 42.17 ± 7.64 years) and weighed more (mean weight in asymptomatic group, 69.89 ± 7.64 kg).[2]

The relative contributions of the muscles during the test conditions in the SAI group and comparison with the asymptomatic group[2] are shown in Figures 2 and 3.

Infraspinatus contribution during resisted isometric ER in SAI group

During ER alone and ER with adduction, the contribution of the infraspinatus was significantly greater at 40% MVIC than at either 10% or 70% MVIC ($P < .001$). The addition of adduction did not significantly change the contribution of the infraspinatus at any load.

Effect of adduction on posterior and middle deltoid ER contributions in SAI group

The addition of adduction did not significantly change the contribution of the posterior deltoid at any load. At 10% MVIC, the use of the adduction strategy significantly reduced the contribution of the middle deltoid ($P = .002$).

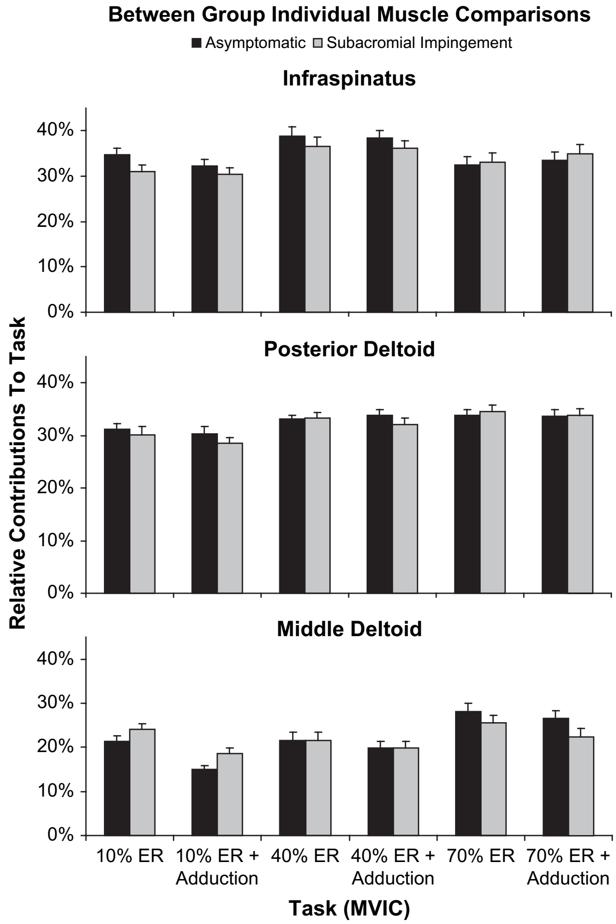

Figure 3 Relative contributions of muscles during experimental tasks (mean + SEM): Between-group individual muscle comparisons.

Comparison of relative muscle activation between SAI group and asymptomatic group

Overall, the patterns of activation in the SAI sample were similar to those found in the asymptomatic shoulders, and there were no differences in the relative contributions of the infraspinatus and the posterior deltoid between the 2 groups. The only apparent difference between the 2 groups was that the contribution of the middle deltoid was significantly greater at 70% MVIC during ER alone and ER with adduction in the asymptomatic group compared with the SAI group ($P = .042$).

During ER alone and ER with adduction, comparison between the 2 groups showed that the contribution from the infraspinatus was significantly greater at 40% MVIC than at either 10% or 70% MVIC ($P < .001$). The addition of adduction did not significantly change the contribution of the infraspinatus in either group at any load. In both groups, the contribution of the posterior deltoid was significantly higher at

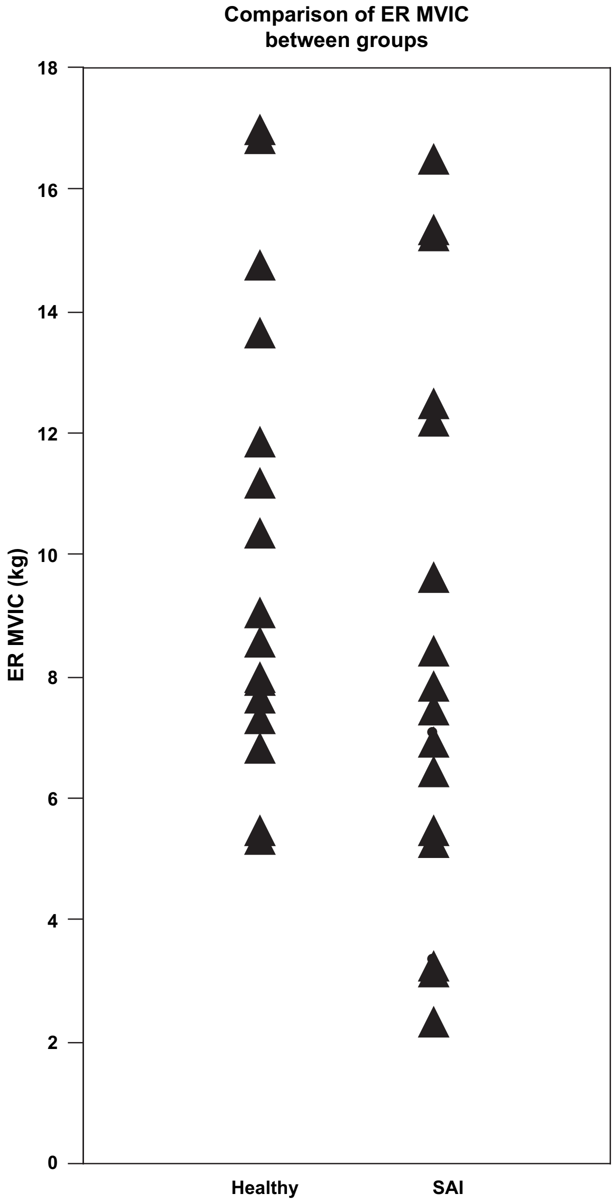

Figure 4 Comparison of ER MVIC between groups.

40% MVIC ($P = .001$) and 70% MVIC ($P < .001$) than at 10% MVIC during ER alone and ER with adduction. The addition of adduction did not significantly change the contribution of the posterior deltoid in either group at any load. However, in both groups, the contribution of the middle deltoid was significantly higher at 70% MVIC than either 10% or 40% MVIC ($P < .001$) for ER alone and ER with adduction. At 10% MVIC, the use of the adduction strategy significantly reduced the contribution of the middle deltoid in asymptomatic shoulders ($P < .001$) and in shoulders with SAI ($P = .002$).

Strength of ER for SAI and healthy subjects

Subjects' ER MVIC findings (in kilograms) are shown in Figure 4. In the asymptomatic group, the MVIC ranged from 5.3 to 17 kg. In the SAI group, the MVIC ranged from 2.3 to 16.5 kg. As a whole, the SAI subjects (mean, 8.239 kg; SD, 4.50 kg) were weaker in ER than the asymptomatic group (mean, 9.856 kg; SD, 3.621 kg), but the notable feature was the greater spread of strengths within the SAI group. Despite the range of measured strengths, the pattern of rotator cuff activation was consistent for all patients in both groups, regardless of their maximum strength.

DISCUSSION

Rotator cuff pathology, and subsequently SAI, is a common cause of shoulder disability and pain in aging populations.[3,16] It has been advocated that individuals with SAI undertake a conservative rehabilitation program.[8,10,17] Conservative physiotherapy programs often use shoulder ER exercises to activate the infraspinatus maximally,[19] but some protocols may also result in high levels of deltoid activity.[19] Thus, some shoulder ER exercise programs may be preferentially activating the deltoid over the infraspinatus and may lead to superior humeral head migration, potentially perpetuating the consequent impingement. The load at which the shoulder ER exercises are set appears to be a critical factor to maximize rehabilitative efforts. If the load is too great, then the deltoid, especially the middle deltoid, may be recruited, resulting in unwanted shoulder elevation and abduction. The ideal conservative rehabilitation program would relatively isolate the infraspinatus from the deltoid, especially in the early stages of rehabilitation.

As with the results in Bitter et al,[2] when interpreting the findings of this study, attention to the method of normalization is necessary. The more common method of normalization to MVIC has problems with reliability and validity[4] and cannot be used in subjects with pain. The method of normalization chosen for this study reveals each muscle's relative contribution to the task. It may appear that a muscle is more active at a lower load, but this is not the case, as the method of normalization indicates both the magnitude of activation of the muscle and its contribution to the task relative to other muscles, not the absolute value.

The findings of this study suggest that, in patients with SAI, performing isometric shoulder ER exercises at 40% MVIC optimizes the contribution of the infraspinatus ($P < .001$) whereas low to medium loads (10%-40% MVIC) of shoulder isometric ER minimize the deltoid contribution. The infraspinatus is an external rotator of the glenohumeral joint[12] and is also an important stabilizing muscle.[5] The physiologic and mechanical properties of the posterior deltoid and middle deltoid support their having a more torque-producing role, as compared with the infraspinatus.[11] As the load of isometric ER increases, the contribution from the deltoid surpasses that of the infraspinatus. This is in keeping with the torque-producing role of the deltoid, the relative contribution of which increases at higher loads as it becomes harder for the infraspinatus to attain the requisite load. The middle deltoid becomes significantly more active at 70% MVIC than at 10% or 40% MVIC ($P < .001$), reflecting a greater abduction moment.

The results also indicate that there was no significant difference between the contribution of the infraspinatus and the posterior deltoid at any load of ER, with or without adduction. This means that the infraspinatus cannot be isolated and rehabilitated separately from the posterior deltoid via isometric shoulder ER exercises. However, the findings do suggest that the infraspinatus can be relatively isolated from the middle deltoid, by use of isometric shoulder ER exercises at low to medium loads with the addition of adduction. The addition of adduction to shoulder ER rehabilitation is thought to reduce activation of the deltoid and relatively isolate the infraspinatus. Whereas Reinold et al[19] did not support the addition of adduction to shoulder ER exercises, analysis of data from both asymptomatic shoulders[2] and symptomatic SAI shoulders demonstrated that the addition of adduction effectively reduced the contribution of the middle deltoid at 10% MVIC. Differences in study design (performing isotonic ER with hand weights) and methodology (normalization to MVIC) may account for the contradictory result.

Interestingly, this study on SAI patients showed very similar patterns of muscle activation with increasing loads of isometric shoulder ER with and without adduction compared with subjects with asymptomatic shoulders. The only difference between the 2 groups was that the middle deltoid was shown to be significantly more active at 70% MVIC during ER alone and ER with adduction in the asymptomatic group than in the SAI group ($P = .042$). This is a somewhat surprising result, but a possible explanation could be that the SAI group may have had more discomfort (not assessed) or fear of discomfort (also not assessed) at the high load and thus failed to activate the middle deltoid maximally.

Patients in the SAI group were weaker and had a greater spread of strengths of ER MVIC. It follows that the load for 10%, 40%, and 70% ER MVIC also varied considerably in both groups (Figure 3). However, regardless of the load of resisted isometric ER that the subject was required to attain, the relative contributions of the muscles stayed the same. Thus, the load that corresponded to 40% MVIC was unique in every subject, and at this load, the contribution of the infraspinatus was optimized. The clinical implication is that regardless of how weak the shoulder is, picking the load of ER that corresponds to 40% MVIC should target the infraspinatus. On the basis of this finding, it can be anticipated that, as the shoulder recovers to normal and the strength of the muscles improves, the relative contributions will stay the same. Reference, therefore, to a standard load is likely to be inappropriate to optimize the rehabilitative efforts. The use of a simple sEMG monitor can demonstrate when the middle deltoid is activated above the infraspinatus and could, therefore, indicate the appropriate initial training level.

sEMG is an objective and noninvasive method of recording the electrical activity of muscle contractions and has been used extensively in research.[4] The main concerns regarding sEMG include reliability, validity, and methods of normalization. sEMG has been shown to be reliable[1,4] but shows poor validity in comparing raw data between muscles, subjects, and days.[4] Normalization reduces the variability in raw data, quantifies the electromyographic signal as a relative percentage, and allows comparison between subjects, muscles, sides, and days.[4] In this study, a method of normalization was chosen that allowed for comparison of an asymptomatic population with a group having pain.[4] However, subjects were required to produce a maximal isometric effort, which may still be a limiting factor, as those with pain may not have fully activated their external rotators. sEMG is also affected by cross-talk, in which the electrodes pick up signals from surrounding muscles.[4] In this study, every effort was made to minimize these concerns by use of small, fixed inter-electrode distances and the recommended placement of electrodes.[4,7,9] To improve consistency, the same investigator positioned the electrodes each time, electrodes were not moved between the test movements, and each subject was tested fully in a single testing session.

It was expected that a difference would be seen between the groups, but this was not the case. The small sample size is likely to have lowered the power for comparison between the 2 groups. Although efforts were made to have demographically homogenous groups with stringent inclusion and exclusion criteria, the SAI group was older and weighed more than the asymptomatic group. These differences may also account for the unexpected similar muscle activation patterns between the 2 groups.

In conclusion, the findings of this study suggest that the most effective early-stage rotator cuff rehabilitation program, in patients with SAI, may be one that uses shoulder ER exercises at low loads with the addition of adduction (<40% ER MVIC) and this should be tailored to each individual shoulder, based on measurement of either MVIC or sEMG recording.

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