Comparative electromyographic analysis of shoulder muscles during planar motions: Anterior glenohumeral instability versus normal

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This study compared the electromyographic activity of rotator cuff and scapular muscles between subjects with anterior instability and subjects with normal shoulders. Thirty-eight patients were studied; 23 had anterior instability that was subsequently surgically confirmed, and 15 had normal shoulders. Fine wire electrodes were inserted into the subscapularis (upper and lower portions), supraspinatus, infraspinatus, rhomboid, serratus anterior, and trapezius (upper and lower portions) muscles. Abduction, scapular plane abduction (scaption), and forward flexion were performed over the range of motion and later divided into 30° intervals. In both abduction and scaption, the supraspinatus demonstrated significantly less electromyographic activity from 30° to 60° in shoulders with anterior instability compared with normal shoulders ($p < 0.05$). During all three motions, shoulders with anterior instability demonstrated significantly less electromyographic activity in the serratus anterior when compared with normal shoulders ($p < 0.05$). This occurred at 30° to 120° of abduction and at 0° to 120° of scaption and forward flexion. None of the other muscles demonstrated significant differences. These differences during planar motions were similar to those demonstrated during challenging overhead sport motions. Early rehabilitation efforts should focus both on the rotator cuff and scapular muscles to establish smooth, coordinated shoulder motion. (J Shoulder Elbow Surg 1996;5:118-23.)

The stabilizing function of the soft tissues of the glenohumeral joint—the joint capsule, glenohumeral ligaments, and glenoid labrum—have been well described.[10, 18, 19] This finite stability, however, also depends on an equally precise and coordinated muscular effort. Muscles responsible for moving the shoulder compress the head of the humerus into the concave surface of the glenoid.[10] Blasier et al.[2] supported this concept of stability by demonstrating that increased force was necessary to dislocate the glenohumeral joint as muscle force increased. Because there is a small area of articular surface contact at the glenohumeral joint, active muscle control is probably more significant at the shoulder than at other joints of the skeleton.[17] Loss of coordinated muscle function may therefore leave the glenohumeral joint unstable. Electromyography (EMG) has revealed that throwing and pitching require a high level of neuromuscular coordination.[9] During this challenging activity, alterations in shoulder muscle EMG firing patterns in individuals with anterior glenohumeral joint instability were reported.[5] Rotator cuff and scapular rotator muscles, the muscle groups responsible for glenohumeral joint stability, demonstrated differences amenable to a conditioning and rehabilitation program. Few individuals actually engage in activity requiring the glenohumeral demands of pitching, so it is desirable to investigate the mechanics of joint instability in those whose activities rarely go beyond that required for daily living.

The purpose of this study was to compare the EMG activity of the rotator cuff and scapular muscles between patients with anterior instability

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and subjects with normal shoulders during three planar motions that are routinely used in activities of daily living. Early detection of altered muscle firing patterns in planar motions may further aid in rehabilitating the individual with an unstable glenohumeral joint.

MATERIAL AND METHODS

Twenty-three patients with anterior glenohumeral joint instability were studied. Age ranged from 18 to 48 years (mean 30.1 years). There were nine left shoulders and 14 right shoulders, and all patients had surgically documented unidirectional, anterior glenohumeral joint instability. EMG testing was done immediately before the surgical stabilization procedure. Fifteen subjects with normal shoulders were studied; age ranged from 23 to 42 years (mean age 32 years). There were six left shoulders and nine right shoulders studied. None of these subjects had a history of or current anterior glenohumeral joint instability.

Dual 50 μm wire electrodes were inserted intramuscularly by the Basmajian[1] single-needle technique. The eight muscles studied were the subscapularis (upper and lower portions), supraspinatus, infraspinatus, rhomboids, serratus anterior, and trapezius (upper and lower portions). One end of the wire electrodes rested within each of the muscles of interest, and the other end connected to a ground plate secured to the patient's body. Correct placement was verified by visual inspection of muscle contraction on an oscilloscope during specific manual muscle testing. Leads from the ground plates were then connected to a telemetry unit so that EMG activity from the muscle could be transmitted to a recorder. The telemetry unit, which was worn around the patient's waist, therefore did not interfere with the shoulder motions being studied.

After recording a resting level of EMG activity for each channel to exclude ambient noise from the EMG recording, a 5-second maximum manual muscle test (MMT) was performed on each of the eight muscles in each subject. The data were later used in the normalization process. Three planar motions of the shoulder were studied with a 3.3 lb weight in the hand: abduction in the coronal plane of the body, abduction 30° anterior to the coronal plane (scaption), and forward flexion.

All subjects were filmed from the lateral view with a 16 mm Redlake LOCAM camera (Redlake, Morgan Hill, Calif.) at approximately 50 frames per second. The film was synchronized with EMG computer files with an electronic pulse that simultaneously marked the film and EMG computer file. Each film was subsequently viewed with a stop-action projector allowing single-frame advancement. The analog EMG signals from the initial manual muscle test (MMT) and the planar motions were transmitted by telemetry to dual multichannel receivers (Model 4200A, BioSentry Telemetry, Torrance, Calif.). The signal was sampled by computer at 2500 Hz with high and low band pass-filter frequencies at 100 and 1000 Hz, respectively. The signal was converted from analog to digital format and recorded on a computer. Within the 5-second MMT of each muscle, the highest one half second interval of integrated EMG signal was selected as 100% effort. The mean EMG activity of the patient for each of the eight muscles was calculated over 30° intervals of the range of motion and expressed as a percentage of the MMT. Integrated EMG for each phase of the three planar motions was averaged within and among subjects and expressed as a mean and standard deviation.

Data were assessed for normality. Muscle activity in normal and unstable shoulders was compared with an independent t test if the data were normally distributed and by a Wilcoxon signed rank test if the data were not normally distributed ($p < 0.05$).

RESULTS

In general, EMG activity during scaption, abduction, and forward flexion increased from the first arc (0° to 30°) to the second arc (30° to 60°) (Tables I and II).

Comparison of muscle activity between normal shoulders and those with anterior joint instability demonstrated significant differences in both the serratus anterior and supraspinatus. The EMG activity of the serratus anterior was significantly less ($p < 0.05$) in the shoulders with anterior joint instability from 0° to 120° of motion for both scaption and flexion (Figure 1*A*, *B*). During abduction, the EMG activity was significantly less ($p < 0.05$) in the shoulders with anterior joint instability from 30° to 120° of motion (Figure 1*C*).

The supraspinatus demonstrated significantly less EMG activity in the shoulders with anterior joint instability when compared with normal shoulders between 30° to 60° of scaption ($p < 0.05$) (Figure 2*A*). During abduction, the EMG activity was significantly less in the shoulders with anterior

Table I Muscle activity in normal shoulders during planar motions (% MMT, mean ± SD)

Phase interval	Supraspinatus	Infraspinatus	Upper subscapularis	Lower subscapularis	Serratus anterior	Rhomboids	Upper trapezius	Lower trapezius
Scaption								
0°-30°	35 ± 17	13 ± 10	17 ± 24	18 ± 13	37 ± 12	8 ± 7	42 ± 21	22 ± 21
30°-60°	52 ± 21	32 ± 23	17 ± 19	21 ± 14	58 ± 19	15 ± 13	59 ± 24	41 ± 35
60°-90°	59 ± 27	34 ± 19	17 ± 15	26 ± 14	66 ± 22	19 ± 18	60 ± 26	44 ± 32
90°-120°	56 ± 36	28 ± 15	20 ± 13	28 ± 13	68 ± 19	23 ± 25	57 ± 23	44 ± 21
Abduction								
0°-30°	33 ± 9	20 ± 10	8 ± 12	5 ± 8	25 ± 16	8 ± 7	32 ± 14	21 ± 18
30°-60°	60 ± 20	33 ± 15	18 ± 22	16 ± 23	44 ± 20	13 ± 11	53 ± 22	29 ± 22
60°-90°	64 ± 24	39 ± 15	23 ± 20	21 ± 15	61 ± 21	23 ± 18	60 ± 26	35 ± 27
90°-120°	61 ± 23	40 ± 16	28 ± 19	25 ± 14	68 ± 21	24 ± 21	63 ± 30	32 ± 24
120°-150°	45 ± 22	42 ± 20	29 ± 14	31 ± 22	66 ± 19	23 ± 21	60 ± 28	28 ± 21
150°-180°	28 ± 19	37 ± 21	20 ± 16	26 ± 25	57 ± 16	17 ± 18	50 ± 23	21 ± 15
Flexion								
0°-30°	35 ± 11	21 ± 6	9 ± 7	4 ± 3	33 ± 15	8 ± 9	25 ± 12	17 ± 12
30°-60°	45 ± 12	39 ± 10	15 ± 9	9 ± 8	57 ± 22	18 ± 17	44 ± 17	30 ± 20
60°-90°	43 ± 13	51 ± 13	14 ± 11	12 ± 8	68 ± 24	23 ± 24	48 ± 17	29 ± 19
90°-120°	40 ± 16	54 ± 13	14 ± 10	15 ± 12	81 ± 24	24 ± 28	53 ± 23	29 ± 15
120°-150°	33 ± 18	48 ± 18	14 ± 10	25 ± 25	82 ± 25	27 ± 27	52 ± 23	34 ± 25
150°-180°	29 ± 25	28 ± 20	14 ± 11	22 ± 26	62 ± 24	22 ± 23	41 ± 21	34 ± 29

Table II Muscle activity in shoulders with anterior instability during planar motions (% MMT, mean ± SD)

Phase interval	Supraspinatus	Infraspinatus	Upper subscapularis	Lower subscapularis	Serratus anterior	Rhomboids	Upper trapezius	Lower trapezius
Scaption								
0°-30°	20 ± 8	10 ± 8	7 ± 7	9 ± 11	17 ± 14	6 ± 9	36 ± 19	17 ± 12
30°-60°	37 ± 13	20 ± 11	13 ± 12	14 ± 13	28 ± 15	13 ± 16	48 ± 21	28 ± 15
60°-90°	41 ± 16	24 ± 14	19 ± 15	18 ± 13	39 ± 17	17 ± 22	56 ± 22	39 ± 20
90°-120°	43 ± 20	20 ± 12	21 ± 17	24 ± 17	50 ± 18	22 ± 28	61 ± 20	47 ± 25
Abduction								
0°-30°	24 ± 12	18 ± 9	6 ± 8	5 ± 6	18 ± 17	4 ± 4	35 ± 22	19 ± 17
30°-60°	42 ± 20	26 ± 11	14 ± 13	10 ± 13	28 ± 19	11 ± 12	41 ± 24	27 ± 17
60°-90°	52 ± 23	31 ± 20	25 ± 16	19 ± 18	40 ± 20	16 ± 21	51 ± 24	39 ± 25
90°-120°	56 ± 22	33 ± 17	33 ± 21	24 ± 15	53 ± 18	21 ± 25	56 ± 24	42 ± 29
120°-150°	49 ± 21	33 ± 17	31 ± 20	25 ± 11	59 ± 25	21 ± 23	53 ± 22	44 ± 23
150°-180°	31 ± 21	27 ± 16	22 ± 24	20 ± 13	57 ± 18	16 ± 16	44 ± 20	34 ± 19
Flexion								
0°-30°	22 ± 13	20 ± 12	5 ± 6	6 ± 10	14 ± 8	4 ± 7	26 ± 12	14 ± 12
30°-60°	32 ± 12	33 ± 12	13 ± 11	15 ± 22	30 ± 12	11 ± 13	32 ± 17	24 ± 15
60°-90°	34 ± 10	44 ± 16	15 ± 12	13 ± 13	45 ± 16	13 ± 14	40 ± 19	29 ± 16
90°-120°	32 ± 9	46 ± 15	15 ± 14	18 ± 12	60 ± 17	15 ± 13	45 ± 19	33 ± 19
120°-150°	28 ± 11	40 ± 13	15 ± 15	20 ± 11	69 ± 25	16 ± 15	42 ± 20	36 ± 18
150°-180°	27 ± 17	34 ± 15	16 ± 21	24 ± 13	63 ± 19	16 ± 16	44 ± 12	39 ± 24

joint instability between 30° to 60° of motion ($p < 0.05$) (Figure 2*B*).

For the other muscles studied, EMG activity was not significantly different in shoulders with anterior joint instability when compared with the normal shoulders over the entire range of scaption, abduction, and forward flexion.

DISCUSSION

During shoulder elevation, EMG activity in the serratus anterior muscle in the shoulders with anterior joint instability was diminished when compared with normal. This indicates an abnormality in the coordinated rotation of the scapula on the thorax (scapulothoracic rhythm). Recognized pri-

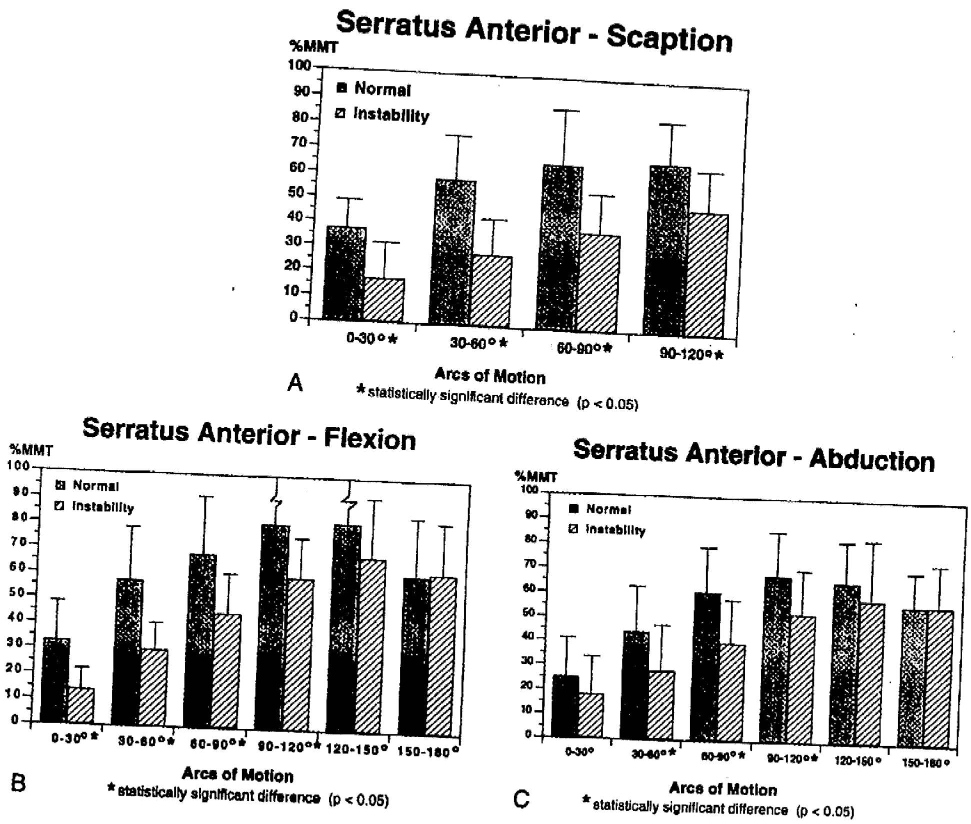

Figure 1 A, Muscle activity in the serratus anterior during scaption in normal and unstable shoulders. **B,** Muscle activity in the serratus anterior during flexion in normal and unstable shoulders. **C,** Muscle activity in normal serratus anterior during abduction in normal and unstable shoulders.

marily as a protractor preventing winging of the scapula, the serratus anterior muscle is also an important rotator of the scapula during shoulder elevation.[1] Normal scapulothoracic rhythm has been extensively studied,[3, 4, 7, 12, 14, 15] and this study shows the normal serratus anterior EMG activity during three common motions in activities of daily living. The pattern of altered serratus anterior EMG activity in shoulders with anterior joint instability indicates how the scapulothoracic rhythm was altered.

In normal shoulders, EMG activity for the serratus anterior muscle was low over the first 30° of shoulder abduction. In an in vivo radiographic evaluation, Poppen and Walker[14] reported that at the initiation of scapular motion with the first 30° of shoulder elevation, the scapula moved little. Most shoulder motion in the first 30° of scaption was at the glenohumeral joint, which rotated four times as much as the scapulothoracic joint. In scaption and forward flexion, over this same range of motion, serratus anterior EMG activity in shoulders with anterior joint instability was diminished when compared with normal. This indicated the serratus anterior may have been less effective in initiating rotation of the scapula in the shoulders with anterior joint instability.

When elevating above 30°, the EMG activity of the normal serratus anterior muscle was high. The scapula is known to move considerably over this range of motion, rotating upward on the thorax an amount equal to the rotation of the humerus on the glenoid.[3, 14, 15] In the shoulders with anterior joint instability, there was significantly diminished EMG activity in the serratus anterior muscle from 30° to 120° of elevation. This finding may indicate decreased serratus anterior function (rotating the scapula) over this range of motion, which may be indicative of the asymmetry in the shoulders with anterior joint instability.

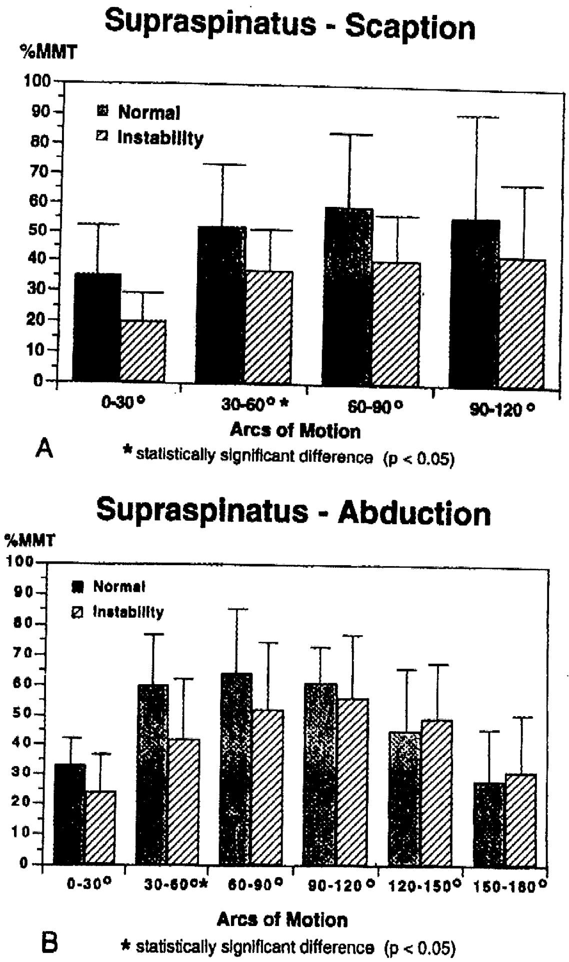

Figure 2 A, Muscle activity in the supraspinatus during scaption in normal and unstable shoulders. **B,** Muscle activity in the supraspinatus during abduction in normal and unstable shoulders.

Other studies have indicated an alteration in EMG activity of the serratus anterior muscle in the injured shoulder. EMG studies during challenging activity such as throwing a baseball have demonstrated similar findings to those in this study. Glousman et al.[5] found that elite pitchers with anterior joint instability had significantly decreased serratus anterior EMG activity in three phases of the pitch when compared with normal. Because of the rapidity of upper extremity motions,[9] observation of scapular motion is nearly impossible during the baseball pitch. But clinical examination of scapular rotation during scaption in many professional pitchers with anterior joint instability has revealed an asymmetry in scapular rotation.

Significantly decreased serratus anterior muscle EMG activity has also been found in swimmers with shoulder pain.[16] During the pulling phase of the freestyle stroke, there was significantly less activity in the serratus anterior in subjects with a painful shoulder when compared with normal subjects. The serratus anterior demonstrates similar findings during the pull-through phase of the butterfly stroke in subjects with a painful shoulder.[13] These studies indicated the importance of the serratus anterior muscle in normal, pain-free shoulder function.

A scapular asymmetry during shoulder elevation may contribute to glenohumeral joint instability by altering the position of the glenoid. The translation of the humeral head is small in normal glenohumeral joint motion,[6, 14] partly because the articular surface of the glenoid acts as a stable base for the humeral head. Itoi et al.[8] demonstrated this important interaction of the joints of the shoulder as translation of the humeral head was diminished when upward rotation of the scapula was increased. The upward rotation of the scapula during normal scapulothoracic rhythm may also act to position the glenohumeral joint for maximum effectiveness of other static glenohumeral restraints. Turkel et al.[19] showed that no single structure was primarily responsible for stability at all positions of the joint. Instead, the structure most responsible depended on the glenohumeral position. With elevation of the injured shoulder, there may be an increase in glenohumeral joint rotation. During abduction with the shoulder at 90°, for example, the humeral head may be in a position that is rotated upward more than normal on the glenoid. The static restraints normally responsible for joint stability may not be in optimal position to limit translation of the humeral head. The abnormal increase in glenohumeral motion may then further stretch or potentially injure the static restraints. Future studies of scapular kinematics are necessary to demonstrate the scapular motion in shoulders with anterior joint instability, as indicated by the altered EMG findings in this study.

In normal shoulders, the supraspinatus forms a force couple with the deltoid to elevate the arm.[7, 11] At the initiation of elevation, the role of the supraspinatus is most critical.[14] At this point the deltoid has a strong upward shearing component, and the supraspinatus functions to counteract that component by delivering a compressive, or even downwardly directed force.[10, 14] As the arm is elevated further, the shear force of the deltoid is diminished and the supraspinatus does not need to produce as much joint compression.[14] Thus it is during the early arcs of elevation that the supraspinatus is most important.

If the supraspinatus was functioning at an abnormally low level, as shown in this study, the upward shearing force of the deltoid would have less counterbalancing force, and the humeral head could rise superiorly. The axis of rotation and congruency of the humeral head on the glenoid would no longer be closely held, and injury could result.

Blasier et al.[2] demonstrated the importance of the supraspinatus muscle in joint stability. With the application of an in vitro model, they found that by eliminating the force of the supraspinatus muscle, there was an 18% reduction in the force necessary to subluxate the joint. Thus if the supraspinatus was not functioning optimally, subluxation could result.

None of the other muscles demonstrated significantly altered activity in the unstable shoulders compared with normal shoulders. This finding may simply indicate that during the planar motions used in activities of daily living, these muscles are not overly challenged. It would appear that they play less of a role in the cause/effect of shoulder instability in the nonoverhead athlete.

The abnormalities in muscle activity in the serratus anterior and the supraspinatus muscles, whether part of the primary pathologic process or caused by it, are part of the complexity of anterior joint instability. On the basis of this information, the importance of strengthening and conditioning these muscles is evident. Both preventative and rehabilitative exercise programs have a basis for focusing efforts on the serratus anterior and supraspinatus muscles in shoulders with anterior joint instability.

SUMMARY

During planar motions, changes are evident in both the serratus anterior and supraspinatus muscle activity in the unstable glenohumeral joint. These muscles, vital to joint stability, position the scapula to maximize glenohumeral joint congruency and keep the humeral head centered on the glenoid. It is meaningful that diminished EMG activity was found in the shoulders with anterior joint instability. Alteration in serratus anterior muscle function may contribute to scapular asymmetry. Diminished activity in the supraspinatus can be detected by strength testing. Both factors are easy to discern at clinical examination and may aid in diagnosing the shoulder with anterior joint instability. In addition, as part of the rehabilitation effort, individuals with anterior glenohumeral joint instability should focus on strengthening and conditioning the serratus anterior and supraspinatus muscles.

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