The effect of limb support on muscle activation during shoulder exercises

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The purpose of this study was to determine the difference in demands on glenohumeral musculature during unsupported and supported active range-of-motion (AROM) shoulder exercises. Twenty healthy subjects volunteered for this study. Surface or fine-wire bipolar electrodes were applied to the infraspinatus, posterior deltoid, anterior deltoid, pectoralis major, and supraspinatus muscles. Subjects performed vertical wall slides and diagonal wall slides (45° angle) with their hand in contact with the wall (supported) and not in contact with the wall (unsupported). Significantly greater supraspinatus activity was found in the unsupported exercises versus the supported exercises ($F_{4,76} = 4.38$, $P = .003$). Exercises performed in the 45° diagonal position were more demanding on shoulder musculature than vertical exercises ($F_{1,19} = 19.3$, $P < .001$). Although our results were obtained in healthy subjects and the implications in a pathological population are not clear, we suggest that when designing a progression of exercises for increasing shoulder muscular activity, supported short lever arm AROM exercises should precede unsupported long lever arm AROM exercises. (J Shoulder Elbow Surg 2004;13: 614-620.)

The goal of rehabilitation after shoulder injury or surgery is to implement a continuum of exercises that restore optimal function while protecting the anatomic integrity of the injured or repaired tissues. The exercises should allow a progression of intensity and load that are within the healing tissue’s capabilities. Excessive early activity produces pain, increases tensile loads, and can increase the inflammatory response, whereas insufficient activity may lead to decreased motion, joint adhesions, and decreased muscle activation. In addition, excessive early activity raises concerns for re-tearing or detachment of the rotator cuff repair. The surgeon and rehabilitation specialists must work together to devise an appropriate rehabilitation program that finds a balance between protecting the repair and regaining range of motion and function.

Ideally, rehabilitation programs should be based on techniques that have been confirmed in the scientific literature. Current literature is particularly helpful during the subacute recovery phase in which resistive exercises are incorporated. Several authors have provided valuable information regarding specific exercises that optimally activate specific shoulder musculature. However, limited research is available to provide guidance in the early phases of rehabilitation. McCann et al evaluated Neer’s 3-phase rehabilitation program of progressing from passive range of motion (PROM) to active range of motion (AROM) and proceeding to resistive exercise to increase the demands on the shoulder musculature gradually. This study provides valuable evidence that PROM exercises performed by a therapist or the patient are less demanding on the shoulder musculature than active-assistive range-of-motion (AAROM) exercises such as a rope and pulley. McCann et al demonstrated that active upright exercises produce less muscular activity than resistive exercises and should be performed before advancing to resistive-type exercises. A key element in rehabilitation is the successful transition in the flow of exercises from the protected PROM exercises of the acute phase to the functional AROM phase. In this evolution, the healing of the tissue is not complete and the musculotendinous tissue cannot tolerate high tensile strains, either from external or from internal force generation. The patient is often anxious to start moving the arm again and will perform active motions with substitution patterns to achieve a semblance of normal function. This time period varies based on surgical intervention and patient history but is typically in the 4-week to 8-week time period after surgery.

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the shoulder musculature during this period should fit into an optimal loading window of stressing the tissue to facilitate strength and increase motion while not overloading the tissue, producing a deleterious inflammatory response, or allowing abnormal movement patterns. The unfortunate result of excessively overloading the tissue might ultimately be cuff repair disruption. This means that the intrinsic muscle activation intensity should be low initially, progressing to higher levels over time, and extrinsic loads should be controlled in a similar manner. Starting with a short lever arm during an arm elevation activity and progressing to a long lever arm activity is one way to adjust the extrinsic load. The immediate environment and speed at which the exercise is performed can be tailored to facilitate strengthening and range of motion without overloading the healing tissue. Kelly et al demonstrated that rehabilitation exercise performed slowly in the water requires less activation of shoulder musculature than the same activity on land. However, a water medium may not be advisable or available for many subjects during their rehabilitation program. One suggested mechanism of controlling the demand placed on the shoulder musculature is to use a form of closed kinetic chain exercises that support the arm during the transition phase. The specific purpose of this study was to investigate the hypothesis that AROM performed with the hand in contact with a stable surface (supported exercise) would be less demanding on shoulder musculature than unsupported AROM exercises. Our overall goal was to continue to identify modes of exercise that provide a smooth transition from passive to active range of motion and ultimately to resisted exercises and do not compromise the musculotendinous integrity of shoulder structures.

MATERIALS AND METHODS

Subjects

Twenty subjects (mean age, 21.7 ± 2.8 years; mean height, 168.6 ± 23.8 cm; mean weight, 73.7 ± 17.1 kg) with normal shoulder function participated in this study. A sample of convenience was recruited from the local university community. Each subject was asked about normal shoulder function. Inclusion criteria for this study included no recent (<6 months) injury to the neck, shoulder, elbow, wrist, or hand that limited sports activity in either recreational or intercollegiate athletics. Exclusion criteria consisted of previous shoulder surgeries, shoulder subluxations, or dislocations. The dominant shoulder, determined as the throwing arm of all subjects, was examined. Before participation, each subject read and signed a consent form approved by the University of Kentucky’s Institutional Review Board (Lexington, KY) after the testing procedures were orally described to them.

Procedures

The subject’s skin was prepared in a standard manner before surface electrode application to minimize electrical impedance. Bipolar surface electrodes (Medicotest, Olstykke, Denmark) were placed over the sternal portion of the pectoralis major, anterior deltoid, posterior deltoid, and infraspinatus in a standardized format to determine muscle activation during the exercises. Each electrode was made of silver/silver chloride with an inter-electrode distance of 2 cm. Sterile bipolar fine-wire electrodes (California Fine Wire, Grover City, CA) were inserted into the belly of the supraspinatus by a 27-gauge hypodermic needle. The 50-μm electrodes were prepared in a standard Basmajian bipolar format. The needle was removed, and the wires were taped down to minimize wire movement.

Maximal voluntary isometric contractions (MVICs) were performed for three 5-second trials for each muscle to normalize electromyographic (EMG) data by use of a previously described protocol. The root mean squared (RMS) peak amplitude of the highest 1-second period of the three MVIC trials was used to represent 100% EMG activity of each muscle. Normalization to 100% muscle activity provides a reference of electrical activity to be reported as a percentage of the MVIC and allows for the data to be statistically compared.

An electrical goniometer (Biometrics, Cwmfelinfach, Gwent, United Kingdom) was used to measure shoulder range of motion of each exercise synchronously with the collection of EMG activity. The speed of arm movement was controlled at 100°/s by the use of a digital metronome (Seiko, Maidenhead, Berks, United Kingdom).

The exercise session consisted of performing AROM exercises in an unsupported (Figure 1) and supported manner and in two positions—vertical (short lever arm) and diagonal (long lever arm) (Figure 2). During the supported AROM exercise portion (vertical and diagonal positions) of testing, an inflated sphygmomanometer cuff was placed between the subject’s hand and a standard slide board that was monitored continuously during the exercise for change in pressure. If the change in pressure was greater than 3 mm Hg, the trial was discarded from further data analysis and the trial was repeated. Previous pilot testing revealed that 3 mm Hg resulted in a 1-lb change in compressive load. Because the slide board surface was identical for both vertical and diagonal exercises in the supported condition, friction differences between the two should have been negligible.

For the unsupported, vertical-position exercise (open kinetic chain), the subject started with the elbow flexed to 90° and the palm of the hand facing the vertical surface, 1 inch away. The arm was then elevated in the scapular plane (45° anterior to the frontal plane) until full elbow extension was achieved while maintaining the 1-inch distance from the wall (Figure 1). The diagonal-position exercise was initiated in a similar position as the vertical position, with the exception that the arm began slightly abducted and externally rotated approximately 45°. Arm elevation was undertaken in the plane of the scapula, again, until full elbow extension was accomplished while maintaining the 1-inch separation from the wall. The supported (closed-
AROM exercises (vertical and diagonal) were done in an identical manner, with the exception that the hand was in contact with, and supported by, the inflated sphygmomanometer cuff on the slide board (Figure 2, A). The order of the exercises and positions was counterbalanced to minimize the effects of fatigue. Counterbalancing allows the investigator to control the order of exercise administration to prevent order biasing that may occur unintentionally if pure random selection is used. A 2-minute rest period was allowed between each exercise set to reduce the influence of fatigue. The two positions studied represent common AROM exercises that are used during shoulder rehabilitation.

EMG data collection and analysis

A Myopac transmitter belt unit (Run Technologies, Laguna Hills, CA) transmitted all raw EMG data at 1000 Hz via a fiberoptic cable to its receiver unit. This device has a common mode rejection ratio of 90 dB. The gain for the surface electrodes was set at 2000, and the gain for the indwelling electrode was set at 1000. The raw data were band-pass-filtered at 20 to 500 Hz and RMS-smoothed with a 30-millisecond time constant by use of Datapac software (Run Technologies). All data were recorded, stored, and analyzed by use of Datapac software on a PC-type computer. For each subject, the three clean trials were averaged and recorded as the mean EMG value for that exercise position. Criteria for a clean trial included no movement artifact, consistent baseline, and a relatively normal bell-shaped goniometric curve. These data were then used for statistical analysis.

Statistical analysis

A 3-way within-factor (position, exercise, and muscle) repeated-measures analysis of variance was performed to compare EMG differences between position (vertical and diagonal), exercise (unsupported and supported), and muscle (supraspinatus, infraspinatus, anterior deltoid, posterior deltoid, and pectoralis major). A Tukey post hoc analysis was performed on any significant analysis of variance findings, and the accepted $\alpha$ level of significance was set at $P < .05$.

RESULTS

Descriptive statistics for the normalized EMG activity for each muscle at each position for both exercises are shown in Table I. No significant 3-way interactions were found. A significant 2-way interaction was found between muscle and exercise ($F_{4,76} = 4.38, P = .003$). No other 2-way interactions were found to be significant. The Tukey post hoc analysis revealed that supraspinatus muscular activity was significantly greater in unsupported AROM exercises compared with the supported AROM exercises ($P < .05$) (Figure 3). Significantly greater EMG activity was found across all muscles in the diagonal position (12.9% ± 4.8%) than the vertical position (9.9% ± 3.3%) ($F_{1,19} = 19.3, P < .01$) (Figure 4).

DISCUSSION

This study supports the practice of using supported AROM exercises before advancing to more demanding unsupported AROM exercises. This type of supported AROM (closed kinetic chain) exercise may be an appropriate intermediate step as patients progress through the continuum from PROM to AROM exercises. The reduction in EMG activity is probably due to an unloading effect and a compressive effect of the supporting surface.

The supporting surface helps to diminish the weight of the arm, thereby decreasing the demand on the
Inman et al suggested that to establish equilibrium at the glenohumeral joint in any position, a minimum of three forces is required: (1) the weight of the arm, (2) the abducting musculature, and (3) the result of the former forces. Thus, by decreasing one component, for example, the weight of the arm, the other two components must decrease to maintain equilibrium. Unloading aquatic exercise has been found to decrease the muscular demand of the rotator cuff because the buoyancy of water decreases the weight of the arm, leading to decreased demands on the shoulder musculature. The advantage of performing supported AROM exercises, such as those used in this study, is that the external load on the arm can be reduced, even when an aquatic environment is not available.

The length of the lever arm is critical to consider in the progression of a shoulder rehabilitation program. The significant differences found in this study between moving the arm in both vertical conditions as compared with both diagonal conditions may be explained entirely by the biomechanical effect of long and short lever arm activity (Figure 4). Otis et al demonstrated that as range of motion increased during scapular elevation to 90°, the lever arm increased. EMG research has demonstrated that as the lever arm increased into a position of abduction, the activity of the deltoid and supraspinatus muscles in-

<table>
<thead>
<tr>
<th>Support AROM</th>
<th>Unsupported AROM</th>
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<tbody>
<tr>
<td><strong>Vertical</strong></td>
<td><strong>Diagonal</strong></td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>12.78 ± 6.64</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>8.61 ± 5.20</td>
</tr>
<tr>
<td>Anterior deltoid</td>
<td>12.34 ± 5.25</td>
</tr>
<tr>
<td>Posterior deltoid</td>
<td>4.69 ± 2.48</td>
</tr>
<tr>
<td>Pectoralis major</td>
<td>6.56 ± 3.41</td>
</tr>
</tbody>
</table>

AROM, active range of motion; EMG, electromyographic; MVIC, maximal voluntary isometric contractions; SD, standard deviation.

Figure 2 A, Photograph illustrating near end position of diagonal wall slides (long lever arm) performed under the condition of supported AROM (with sphygmomanometer). The arm is elevated in the scapular plane (45°) until full elbow extension is achieved. The inset illustrates an overhead view of 45° subject orientation to the slide board in order to keep humeral motion in the scapular plane. B, Photograph illustrating starting position of diagonal wall slides (long lever arm) performed under the condition of unsupported AROM (without sphygmomanometer). The arm begins slightly abducted and externally rotated to approximately 45° with the elbow flexed and elevation occurring in the scapular plane.
A progressive shoulder rehabilitation exercise program should begin with short lever arm activities (elevation in vertical direction) to minimize demand on the glenohumeral musculature and then progress to longer lever arm activities (elevation in diagonal direction). In our study, the vertical-position exercise (undertaken primarily in the scapular plane) started in a position of 90° elbow flexion with the hand at waist level. This position keeps the hand close to the body and the elbow relatively flexed through most of the exercise, which in turn makes this primarily a short lever arm activity. The diagonal exercise, though starting in the same general position, required the subject to slide or raise the arm up and along a diagonal slope of 45°, moving the hand away from the body. At end range, the elbow was in full extension with the humerus approximating 90° (110° ± 10°) of elevation in the scapular plane and slight external rotation. This long lever arm activity placed greater demands on the shoulder musculature, resulting in higher EMG activity, supporting the finding of previous biomechanical and EMG studies. On the basis of the results of this study, it appears that initiating supported AROM exercises by use of short lever arm activities such as vertical wall slides would be indicated to minimize demand on the supraspinatus musculature while providing an exercise to enhance shoulder range of motion.

The resultant compressive forces provided by the rotator cuff and deltoid musculature provide stability and mobility at the glenohumeral joint. Disruption of rotator cuff tissue compromises the resultant compressive force and diminishes motion. Incorporation of resultant compression externally by a supported AROM exercise in vivo may produce humeral compression into the glenoid similar to cadaveric models. This concept of increasing joint compression forces resulting in less demand on the muscle activity has been demonstrated experimentally in the hip. Although there was no attempt to measure compressive resultant forces during this study, it is plausible to assume some occurred during the supported AROM condition, which may have contributed to the diminished demand on the shoulder musculature. The effect of joint compression on muscular demands about the shoulder is worthy of further investigation.

When comparing this study’s results with previous shoulder rehabilitation research, an exercise continuum can begin to be constructed. Caution should be taken when comparing results between different EMG studies because of normalization procedures, electrode type, placement, data analysis, subject popula-
tion, and various EMG processing methods. However, comparing various studies allows clinicians to appreciate the demands various exercises place on the shoulder musculature. EMG values for the glenohumeral and scapular musculature during PROM exercises have very low levels of normalized EMG activity—less than 5% MVIC. Scaption (humerol elevation in the scapular plane) in an aquatic medium has been shown to be slightly more demanding than PROM exercises, with EMG values ranging from 2% to 10% MVIC for the glenohumeral musculature. In some situations, aquatic therapy may not be advisable; therefore, incorporation of supported AROM exercises, similar to this study, which ranged from 4% to 18% MVIC, can serve as an appropriate alternative exercise to gradually increase demand on the shoulder musculature in general and the rotator cuff in particular. Resisted forward elevation below the shoulder level with an elastic band has resulted in EMG activity ranging from 24% to 41% MVIC. Open kinetic chain scaption exercise in full elbow extension with moderate resistance has been found to produce activity levels equal to 72% to 74% of an MVIC in the supraspinatus and anterior deltoid. Therefore, the exercises performed in this study are of a relatively lower demand on the shoulder musculature and would be appropriate in the earlier phases of a rehabilitation program. The large separation in muscle demand between exercises studied in this investigation and other resistive exercises studied indicates that further research is necessary to provide health care professionals with a scientifically based continuum of shoulder rehabilitation exercises.

Although this study only examined five shoulder muscles, incorporation of more muscles in future research would certainly increase the understanding of all muscular demands during rehabilitation exercises. The investigation in this study, as in previous research, only examined healthy shoulders. Given this limitation, caution should be used in applying these results to an injured population. Clinical experience with these techniques has revealed that patients tolerate the supported exercises well, with appropriate consideration given to the surgical procedure. Continued investigation must incorporate injured patients during the rehabilitation process, because these patients have pain and substitution movement patterns that would probably affect muscular activation patterns.

This study provides some evidence to support a
logical progression from PROM to AROM exercises. It is hoped that the information from this investigation will help health care professionals in prescribing a safe progression from low-demand to higher-demand shoulder exercises and assist in devising an evidence-based exercise continuum.

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REFERENCES