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The Most Effective Exercise for Strengthening the Supraspinatus Muscle

Evaluation by Magnetic Resonance Imaging*

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ABSTRACT

Background: Electromyography has been used to determine the best exercise for strengthening the supraspinatus muscle, but conflicting results have been reported. Magnetic resonance imaging T2 relaxation time appears to be more accurate in determining muscle activation.
Purpose: To determine the best exercises for strengthening the supraspinatus muscle.
Study design: Criterion standard.
Methods: Six male volunteers performed three exercises: the empty can, the full can, and horizontal abduction. Immediately before and after each exercise, magnetic resonance imaging examinations were performed and changes in relaxation time for the subscapularis, supraspinatus, infraspinatus, teres minor, and deltoid muscles were recorded.
Results: The supraspinatus muscle had the greatest change among the studied muscles in relaxation time for the empty can (10.5 ms) and full can (10.5 ms) exercises. After the horizontal abduction exercise the change in relaxation time for the supraspinatus muscle (3.6 ms) was significantly smaller than that for the posterior deltoid muscle (11.5 ms) and not significantly different from that of the other muscles studied.
Conclusion: The empty can and full can exercises were most effective in activating the supraspinatus muscle.

Strengthening of the rotator cuff muscles, especially the supraspinatus muscle, is one of the most integral parts of a rehabilitation program for athletes with shoulder problems who are involved in overhead throwing sports. Jobe and Moynes[19] suggested that abduction in the scapular plane with internal rotation, the so-called empty can exercise, is the optimal position for isolating the supraspinatus muscle for strengthening and manual muscle testing. However, Blackburn et al.[5] reported that the prone position with the elbow extended and the shoulder abducted to 100° and externally rotated produced the greatest amount of EMG activity in the supraspinatus muscle. Kelly et al.[24] reported that there was no significant difference in supraspinatus muscle EMG activation between abduction in the scapular plane with internal rotation and abduction in the scapular plane with external rotation. These divergent results can be attributed to several factors, such as characteristics of the subjects, testing procedure used, and EMG analysis. Although a higher level of EMG reproducibility was reported by Kelly et al.,[24] shortfalls with the use of EMG still exist. The intramuscular dual fine wire electrodes used in EMG detect the activity of only a small number of muscle fibers and sometimes migrate during exercise. This may help explain the relatively poor reproducibility of EMG[15,25,29] and may be another possible reason for the divergent data.

Increases in muscle proton spin-spin relaxation time (T2) have been shown to correlate positively with activation intensity for concentric and eccentric muscle contractions.[1,10,13,34] Furthermore, the relationship between proton T2 relaxation time and contraction amplitude is linear. These findings indicate that MRI can be used to study skeletal muscle function, with T2 relaxation time serving as a quantitative index of activation. Researchers in several studies have tabulated changes in muscle T2 relaxation times to monitor the pattern of muscle recruitment during various exercises in human subjects.[1,9,10,12,16,32,34,38]

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The purpose of the present study was to determine the most effective exercise for the supraspinatus muscle by using MRI to measure T2 relaxation time for the rotator cuff and deltoid muscles before and after three types of exercise.

MATERIALS AND METHODS

Subjects

Six male subjects without shoulder problems volunteered to participate. Their average age was 25.8 years (range, 25 to 29), average height was 167.0 cm (range, 161 to 180), and average weight was 65.8 kg (range, 62 to 72). All subjects were familiar with the three types of exercises studied and all were given instructions before starting the study.

Exercise Protocol

Three types of exercise were performed: 1) the empty can exercise, in which subjects abducted their arm to 90° in the scapular plane with internal rotation[19] (Fig. 1A), 2) the full can exercise, in which subjects abducted their arm to 90° in the scapular plane with external rotation[17,24] (Fig. 1B), and 3) the horizontal abduction exercise, in which subjects started in a prone position with 90° of shoulder flexion and horizontally abducted their arm with external rotation until their arm was parallel to the floor. At the end point of this last exercise, the arm is in 100° of abduction to the trunk[5] (Fig. 1C). A wrist weight of 20 repetitive maximum was used for each exercise.[8] The weight representing a 20 repetitive maximum (that is, the weight at which the subject can perform only 20 repetitions) was determined for each subject at least 1 week before MRI examination. Three sets of each exercise, separated by 2 minutes of rest, were performed, with each set consisting of 15 repetitions. Exercises were performed at the MR imaging facility so that imaging could be performed before and immediately after exercise. The three types of exercise with MRI examinations were performed at 1-week intervals, and the order of exercise types was randomized.

Imaging Technique

Magnetic resonance imaging of the subjects' shoulders was performed before and immediately after the exercise. Oblique sagittal MR images were acquired with a 1.0-T MRI scanner (Shimadzu, Kyoto, Japan) with a dedicated shoulder extremity coil supplied by the same manufacturer. Subjects were placed in a supine position, and the humerus was positioned in internal rotation. Two T2-weighted images were collected (repetition time, 2000 ms; echo time, 20 and 90 ms). A 256 × 256 matrix was acquired with one excitation and a 20-cm field of view. Total collecting time was 3 minutes, 20 seconds. Twelve 4-mm slices were collected at 1-mm intervals. An ink mark was made at the lateral margin of the acromion to ensure a similar shoulder joint position in the magnet bore between repeated images. Images for calculation were created from these two T2-weighted images.

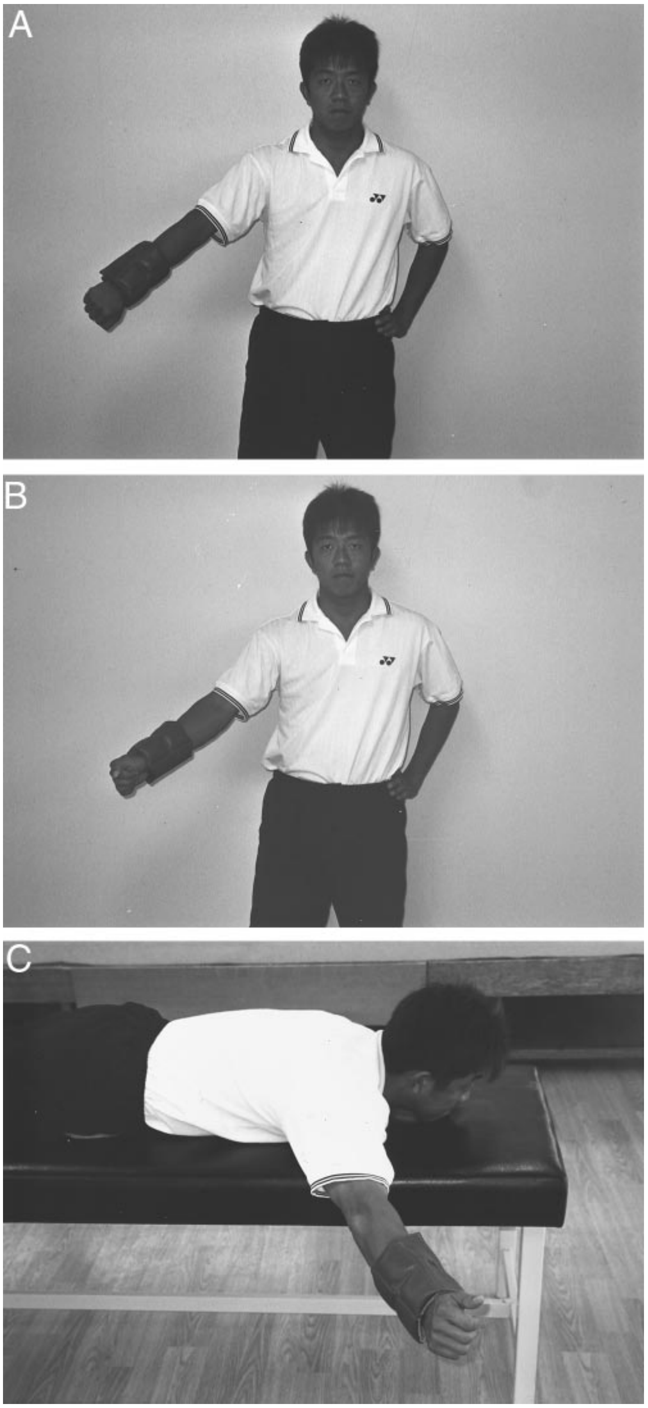

Figure 1. The three exercises used: A, empty can exercise; B, full can exercise; C, horizontal abduction exercise.

Data Analysis

Relaxation time values before and after exercise were measured in a region of interest (region of interest; 42

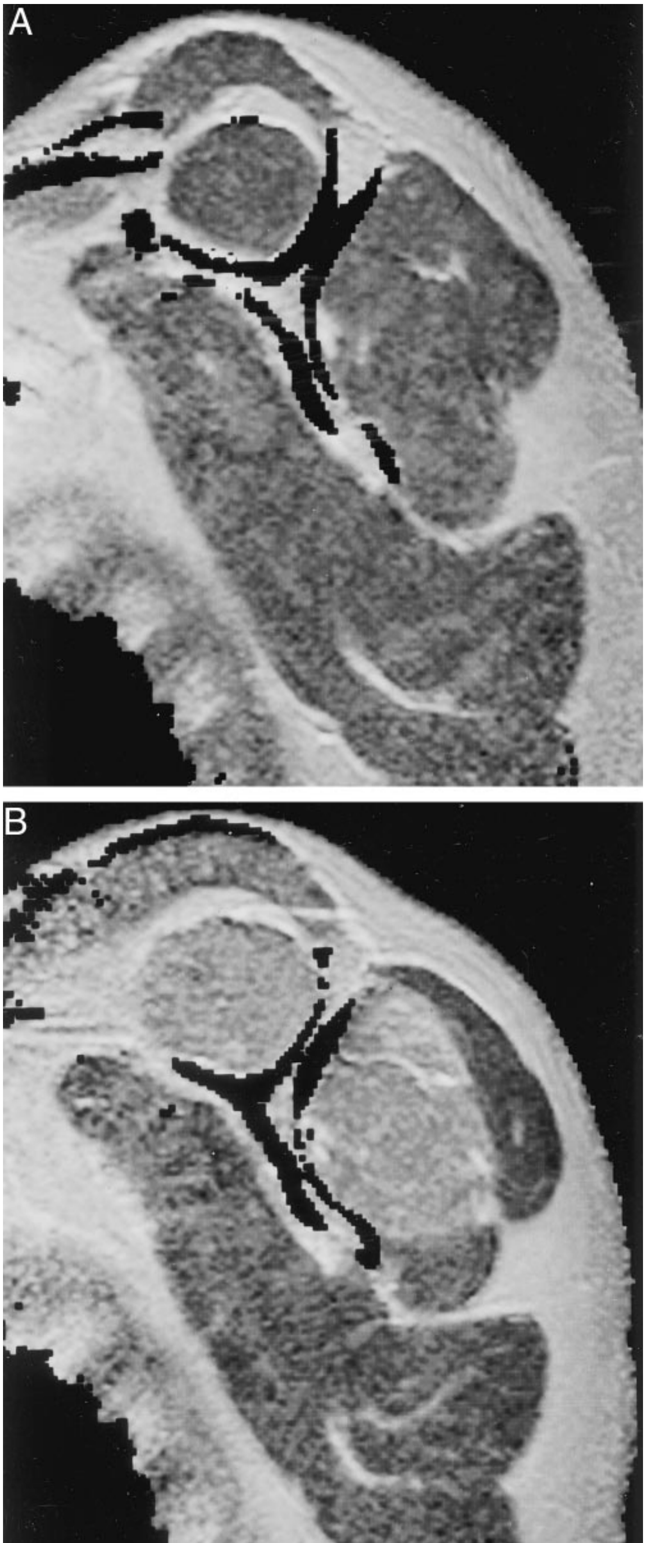

Figure 2. The T2-weighted calculated oblique sagittal images before (A) and after (B) the empty can exercise. Relaxation time for the supraspinatus muscle was 29.0 ms (before the exercise) and 42.0 ms (after the exercise) for this subject.

TABLE 1
T2 Relaxation Times for Rotator Cuff and Deltoid Muscles after the Empty Can Exercise[a]

Muscle	Preexercise	Postexercise	Change
Subscapularis	31.5 ± 1.5	33.5 ± 1.0	2.0 ± 0.8
Supraspinatus	30.0 ± 1.6	40.5 ± 1.4	10.5 ± 2.0[b]
Infraspinatus	31.5 ± 2.5	40.4 ± 3.5	8.9 ± 2.1
Teres minor	31.3 ± 1.3	33.2 ± 1.1	1.9 ± 1.0
Deltoid			
Anterior	29.5 ± 1.8	34.7 ± 4.3	5.2 ± 2.7
Middle	32.3 ± 3.0	41.5 ± 2.2	9.2 ± 2.6
Posterior	30.2 ± 0.9	34.5 ± 3.2	4.3 ± 3.3

[a] Data are given as means ± SD.
[b] Significantly different from the subscapularis, teres minor, posterior deltoid, and anterior deltoid muscles.

mm^2) within the muscles. Each region of interest was selected to avoid any visible blood vessels or fat. Two to three regions of interest were selected for each muscle. Relaxation times were measured for the subscapularis, supraspinatus, infraspinatus, and teres minor muscles and the anterior, middle, and posterior portions of the deltoid muscle before and after each exercise. Relaxation time was measured on the same image for all muscles except the anterior and middle portions of the deltoid muscle. Calculations were performed using software provided with the Shimadzu system. Statistical analysis of the data was performed using one-factor analysis of variance ($P < 0.05$) and a post hoc test (Tukey-Kramer).

RESULTS

Subjects lifted a mean load of 5.8 ± 0.8 kg for the empty can exercise, 6.7 ± 1.0 kg for the full can exercise, and 4.4 ± 0.8 kg for the horizontal abduction exercise. After the empty can exercise, the supraspinatus muscle had the largest increase in T2 relaxation time among the shoulder muscles (Fig. 2). The increase in relaxation time for the supraspinatus muscle was significantly greater than that for the subscapularis, teres minor, and anterior and posterior deltoid muscles (Table 1). The supraspinatus muscle also had the largest increase in relaxation time after the full can exercise (Fig. 3). The increase in T2 relaxation time values for the supraspinatus muscle was significantly greater than the increase observed for the subscapularis, teres minor, and posterior deltoid muscles (Table 2). On the other hand, after the horizontal abduction exercise (Fig. 4), the increase in relaxation time for the supraspinatus muscle was significantly smaller than the increase observed for the posterior deltoid muscle and was not significantly different from the values for the other muscles (Table 3).

The increase in T2 relaxation time values for the supraspinatus muscle after the empty can and full can exercises was significantly greater than that observed after the horizontal abduction exercise (Fig. 4). Increases for the anterior and middle portions of the deltoid muscle after the empty and full can exercises also were significantly greater than after the horizontal abduction exercise, whereas increases for the posterior deltoid muscle

Figure 3. The T2-weighted calculated oblique sagittal images before (A) and after (B) the full can exercise. Relaxation time for the supraspinatus was 30.5 ms (before the exercise) and 41.3 ms (after the exercise) for this subject.

TABLE 2
T2 Relaxation Times for Rotator Cuff and Deltoid Muscles after the Full Can Exercise[a]

Muscle	Preexercise	Postexercise	Change
Subscapularis	32.1 ± 0.7	32.5 ± 1.3	0.4 ± 1.5
Supraspinatus	30.5 ± 1.1	41.0 ± 1.2	10.5 ± 2.0[b]
Infraspinatus	31.5 ± 1.0	40.0 ± 1.9	8.5 ± 2.2
Teres minor	32.2 ± 1.4	33.2 ± 1.9	0.9 ± 2.4
Deltoid			
Anterior	29.1 ± 2.4	36.0 ± 3.2	6.9 ± 2.6
Middle	32.4 ± 3.3	40.8 ± 2.3	8.5 ± 1.6
Posterior	31.0 ± 2.0	30.9 ± 1.5	−0.1 ± 1.7

[a] Data are given as means ± SD.
[b] Significantly different from the subscapularis, teres minor, and posterior deltoid muscles.

after the empty and full can exercises were significantly smaller than those observed after the horizontal abduction exercise (Fig. 5). No significant difference was seen in the increase in relaxation time values for all rotator cuff muscles between the empty can and full can exercises. The increase in relaxation time for the posterior deltoid muscle after the empty can exercise was significantly greater than after the full can exercise, whereas the increase for the anterior deltoid muscle after the empty can exercise tended to be smaller than the increase after the full can exercise (although this was not statistically significant).

DISCUSSION

Jobe and Moynes[19] suggested that having subjects elevate their arm in the scapular plane with the humerus in internal rotation is the best way to isolate the supraspinatus muscle for strengthening and manual muscle testing. Since their report, this exercise has been used most often for these purposes. Townsend et al.[36] reported that this exercise is second to the military press for exercising the supraspinatus muscle and that it had a peak value of 74% in the maximum manual muscle strengthening test. However, Blackburn et al.[5] found that the prone position with the elbow extended and the shoulder abducted to 100° and externally rotated produced the greatest amount of EMG activity in the supraspinatus muscle. Worrell et al.[37] supported the results of Blackburn et al., reporting that the horizontal abduction exercise produced significantly greater EMG activity in the supraspinatus muscle than did the empty can exercise, although the absolute root mean square difference between the two exercises was relatively small. Malanga et al.[27] also compared the EMG activity in the supraspinatus muscle between the empty can exercise and horizontal abduction exercise and found no significant difference between the two. Kelly et al.[24] reported no significant difference in supraspinatus muscle EMG activation between the empty can and full can positions, although slightly less activation of the infraspinatus muscle was noted with the full can position. This would make the latter superior for isolation of the supraspinatus muscle.

These controversies about optimal exercise position for isolating the supraspinatus muscle for strengthening and for manual testing may be caused by differences in subject

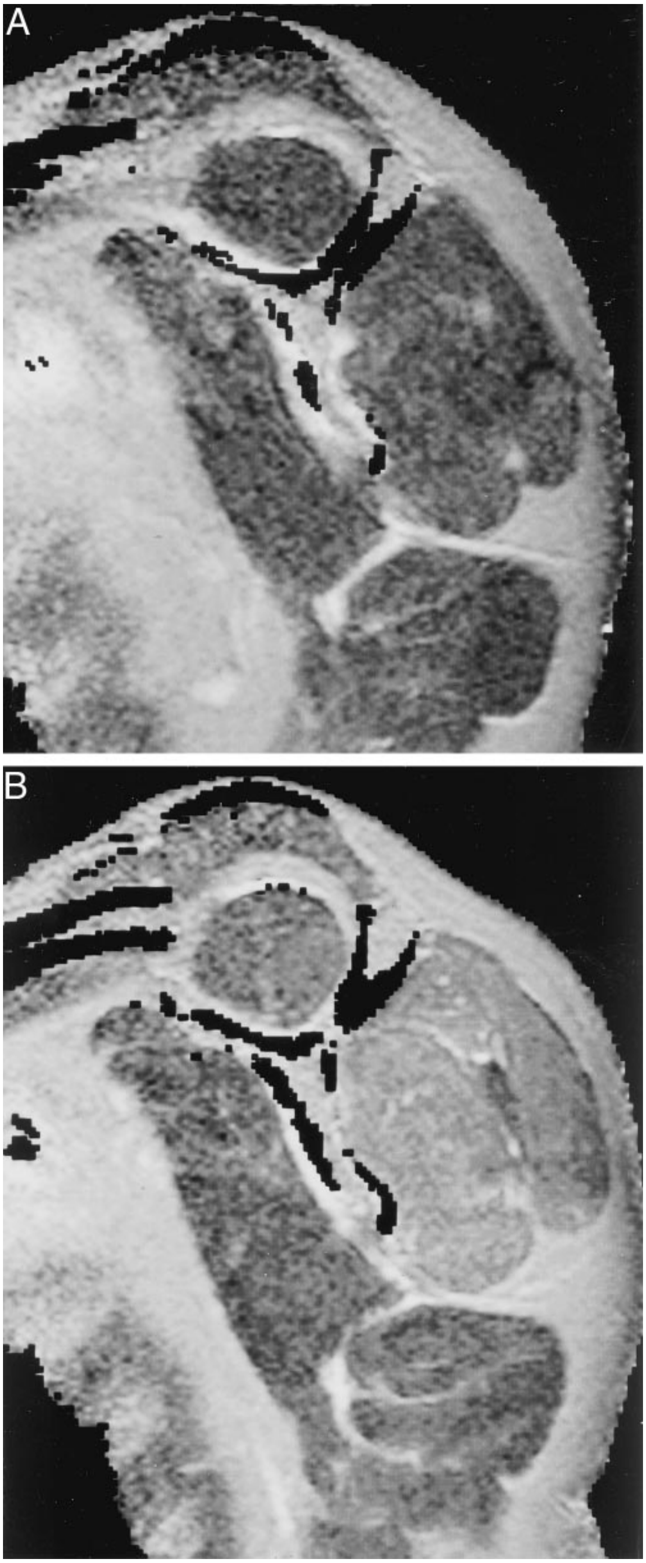

Figure 4. The T2-weighed calculated oblique sagittal images before (A) and after (B) the horizontal abduction exercise. Relaxation time for the supraspinatus was 29.0 ms (before the exercise) and 34.3 ms (after the exercise) for this subject.

TABLE 3
T2 Relaxation Times for Rotator Cuff and Deltoid Muscles after the Horizontal Abduction Exercise[a]

Muscle	Preexercise	Postexercise	Change
Subscapularis	31.5 ± 1.5	31.5 ± 1.2	0.3 ± 1.4
Supraspinatus	30.2 ± 1.4	32.7 ± 2.8	3.6 ± 1.3[b]
Infraspinatus	30.5 ± 1.3	37.1 ± 2.3	6.6 ± 2.9
Teres minor	30.9 ± 1.3	36.4 ± 3.2	5.1 ± 3.8
Deltoid			
Anterior	28.3 ± 2.5	28.8 ± 1.9	0.7 ± 1.5
Middle	31.3 ± 1.9	35.4 ± 3.2	4.4 ± 3.5
Posterior	29.7 ± 0.9	41.3 ± 2.2	11.5 ± 2.4

[a] Data are given as means ± SD.
[b] Significantly different from the posterior deltoid muscle.

characteristics (such as age, height, weight, and athletic ability), testing procedure (isometric versus isotonic), and EMG data analysis (percent maximum voluntary contraction versus integrated EMG). Another explanation for the disagreements involves the relatively poor reproducibility of EMG measurements. Intramuscular wire EMG is widely used for the study of rotator cuff muscle activation. Such electrodes monitor a very small area of detection, corresponding to a small number of individual muscle fibers.[21,25,27,29] Therefore, a small difference in electrode placement on the same muscle may result in significantly different recorded EMG values. Moreover, migration of electrodes sometimes occurs during an exercise experiment, which also affects the results of EMG studies.[29]

Exercise is known to produce changes in the amount and distribution of water in skeletal muscle. Submaximal exercise increases total muscle water content, primarily in the extracellular space, whereas more severe exertion leads to increases in intracellular water.[26,35] Because T2 relaxation time in MRI is highly sensitive to changes in water distribution, several studies have exploited changes in muscle T2 relaxation times to monitor the pattern of muscle recruitment in human subjects during various exercises.[2,10,11,33]

In 1988, Fleckenstein et al.[12] reported that active and inactive muscles could be clearly distinguished on MRI after handgrip exercise. Their study demonstrated an apparent increase in the flexor digitorum profundus muscle relaxation time from 28 to 35 ms, an increase from 28 to 34 ms in the flexor digitorum superficialis muscle, and no significant increase in the flexor carpi radialis and ulnaris muscles. Fisher et al.[10] also demonstrated that active ankle dorsiflexion significantly enhances the contrast between the anterior compartment muscles and the lateral and posterior compartment muscles. Moreover, they reported a high correlation between T2 relaxation time for the tibialis anterior muscle and its generated force (correlation coefficient, $r = 0.87$). In a study by Adams et al.,[1] the subjects performed the dumbbell curl with a weight of 40%, 60%, 80%, and 100% of the 10 repetition maximum. After the exercise, the relative resistance and T2 relaxation time for the biceps brachii muscle were found to be significantly correlated ($P < 0.05$, $r = 0.99$). Since these studies were published, measurements of T2 relaxation time in muscle after exercise have been used to determine muscle use for the biceps brachii muscle,[34] triceps brachii

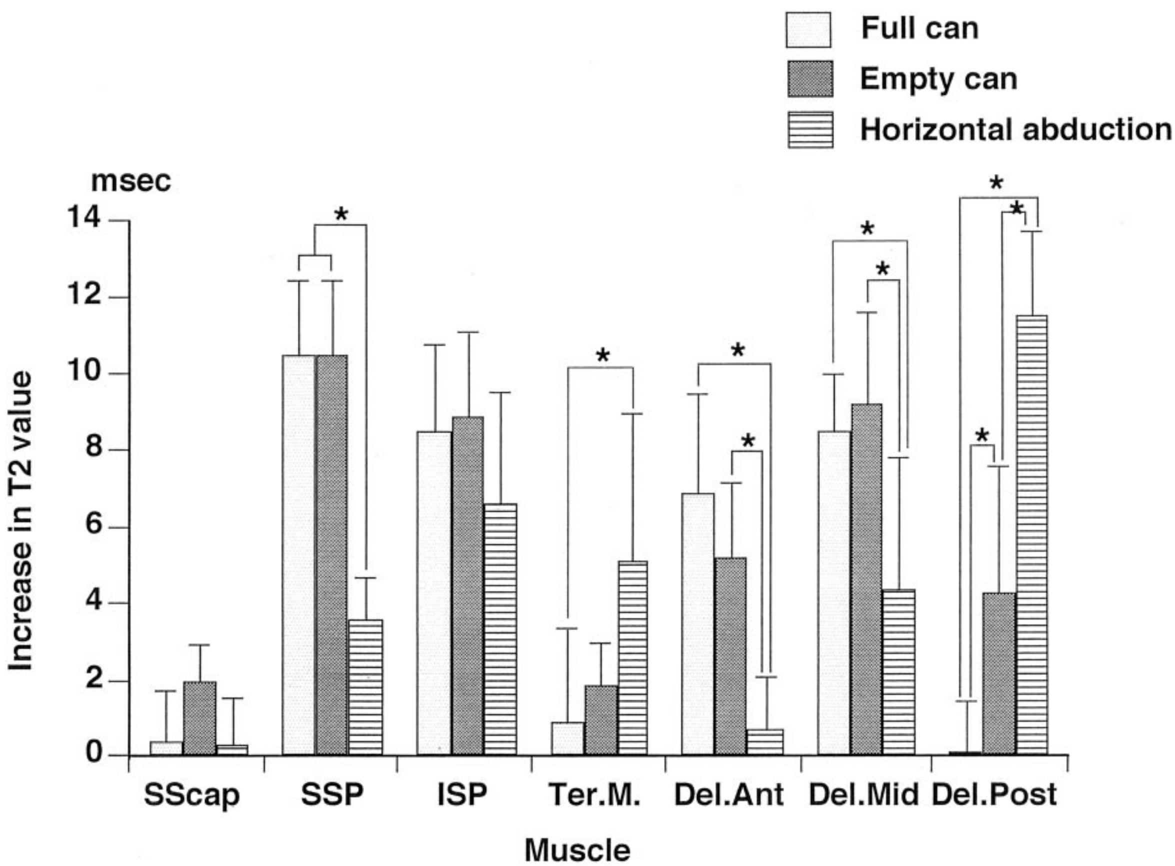

Figure 5. Increased relaxation times after empty can, full can, and horizontal abduction exercises. Asterisks indicate statistically significant differences ($P < 0.05$). SScap, subscapularis muscle; SSP, supraspinatus muscle; ISP, infraspinatous muscle; Ter.M., teres minor muscle; Del.Ant., anterior deltoid muscle; Del.Med., middle deltoid muscle; Del.Post., posterior deltoid muscle.

muscle,[33] forearm muscles,[11] back muscles,[14] quadriceps femoris muscles,[4,31] and ankle dorsiflexors and plantar flexors.[9,18] Increases in signal intensity for the shoulder after exercise also have been reported.[7,16]

Measurements of T2 relaxation time during exercise for determining muscle recruitment have some advantage over intramuscular wire EMG study. One of the biggest advantages is that we can know the muscle recruitment for any muscle and any portion of a muscle easily and noninvasively. With intramuscular fine-wire EMG, the accurate placement of electrodes in the rotator cuff muscles, especially in the subscapularis muscle,[20] is sometimes difficult, and examination of several portions of the same muscle is time-consuming. Another advantage of the MRI method is that it can provide anatomic as well as physiologic information. Akima et al.,[4] in an investigation of the effect of short periods of isokinetic resistance training on muscle use and strength, reported an increase in both the cross-sectional area of the quadriceps femoris muscle and in the T2 relaxation time for the same muscle, as determined from axial MRI images.

High reproducibility of results is another advantage of the MRI method over intramuscular wire EMG study. Komi and Buskirk[25] examined the reliability of measurements with intramuscular wire EMG in submaximal and maximal isometric contractions of the biceps brachii muscle and reported that the intraclass correlation coefficient (ICC) for intrarater reliability was 0.22. Morris et al.[29] examined the coefficient of variation (in percents) of the signals from each of three electrodes that had been inserted 1 cm apart around the recognized points of the rotator cuff muscles during isokinetic exercises. They reported that there was a marked and unacceptable variation (53% for overall mean coefficient of variation) between the three electrodes when the EMG signal was normalized by using the pretest maximum voluntary contraction. Kelly et al.,[24] however, reported a high test-retest reliability of integrated EMG values for rotator cuff muscles tested twice in the same day. The reliability coefficient of the full can exercise with isometric contraction was 0.87 and that of the empty can exercise was 0.84. This high reliability was made possible because of the identification of the optimal exercise for eliciting maximal voluntary contractions[23] and because of technical improvement.[22]

Before beginning the present study, we examined the repeatability of T2 relaxation time measurement for the supraspinatus muscle with the Bland and Altman[6] test. For the interrater reliability of the T2 relaxation time measurement in the supraspinatus muscle after the full can exercise, the Bland and Altman test results showed good agreement (95% confidence interval [CI] for the mean difference, −0.72 to 0.62; reliability coefficient, 0.69). For the between-days repeatability, the results indicated reasonable agreement (95% CI for the mean difference, –1.92 to 0.92; reliability coefficient, 3.53).

Despite all of its advantages, there are some disadvantages of the MRI measurement technique. It takes at least 30 minutes for the increased T2 relaxation time values to return to the preexercise stage.[10] Thus, it takes a long time to measure T2 relaxation time for the same muscle after different exercises. In the present study, therefore, measurements after different exercises were performed on different days. Another disadvantage is that it is difficult to monitor the relaxation time change in real time. It is only possible with echo-planar MR imaging.[3] However, to obtain images with echo-planar MRI, subjects must perform their exercise in a magnet bore, and the shoulder exercises used in the present study may be impossible to perform in a magnet bore.

The present study demonstrates that increases in T2 relaxation time for the supraspinatus muscle after the empty can and full can exercises were significantly greater than increases after the horizontal abduction exercise. Increased relaxation time for the supraspinatus muscle after the three types of exercises studied also could be compared with values for the other rotator cuff muscles and the deltoid muscle in the same subject without any normalization. As a result, T2 relaxation time for the supraspinatus muscle showed a greater increase than that seen for the other muscles after the empty can and full can exercises. In contrast, the increase of T2 relaxation time for the supraspinatus muscle after the horizontal abduction exercise was significantly smaller than the increase for the posterior deltoid muscle, and it did not differ significantly from the increase for other muscles. These results indicate that the empty can and full can exercises are more useful than horizontal abduction for selective strengthening of the supraspinatus muscle, despite the EMG observations of Blackburn et al.[5] and Worrell et al.[37] Worrell et al. speculated that the horizontal abduction exercise places the deltoid muscle in a less-than-optimal length-tension relationship, thus allowing better isolation of the supraspinatus muscle. However, these authors did not measure EMG activity in the deltoid muscles. The present study demonstrated that the T2 relaxation time increase for the posterior deltoid muscle after horizontal abduction was the greatest increase among the shoulder muscles and was significantly greater than the increase observed in the posterior deltoid muscle after the empty can and full can exercises. These results suggest that horizontal abduction in the prone position actually may place the posterior deltoid muscle in the optimal length-tension relationship.

According to Worrell et al., the maximal isometric force production for the horizontal abduction exercise was significantly smaller than that for the empty can exercise (0.84 ± 1.29 kg and 3.9 ± 2.68 kg, respectively). Therefore, if the same weight was used for both exercises, it might be too heavy for the horizontal abduction exercise or too light for the empty can exercise. To load the shoulder muscles effectively in each exercise, we used the repetitive maximum,[8] which is the maximum load lifted in a given number of repetitions before fatigue. Five or fewer repetitions with weight based on a low repetitive maximum (1 to 5 repetitive maximum) provide the most strength and power benefits. Weight based on a 6 to 12 repetitive maximum provides moderate gains, and weight based on a 20 repetitive maximum or higher provides muscular endurance gains without strength gains.

Davis and Donatelli[8] recommend performance of the empty can exercise and horizontal abduction in the prone position using a weight equivalent to 80% of 1 repetitive maximum (equivalent to 10 repetitive maximum) for patients in the middle phase of the rehabilitation program for rotator cuff tendinitis. In the present study, subjects performed the three types of exercises with weights representing a 20 repetitive maximum because we wanted to focus on muscle endurance. However, in a clinical setting, lighter weights than those used in the present study are commonly used. This may raise the question of whether the T2 relaxation time change for the shoulder muscles is affected by the weight used for exercises.

To answer this question, and as an additional investigation, we had three of the six participants in the present study perform the empty can, full can, and horizontal abduction exercises with a weight of 2 kg. The results with a weight of 2 kg were not different from those with heavier weights, although, with the 2-kg weight, the absolute values in T2 relaxation time for each muscle were smaller. With a weight of 2 kg, the increase in relaxation time for the supraspinatus muscle after the empty can (5.9 ± 0.9 ms) and full can exercise (5.3 ± 1.2 ms) was much greater than that after the horizontal abduction exercise (1.6 ± 0.8 ms). After the horizontal abduction exercise, the posterior portion of the deltoid muscle showed a significant increase in relaxation time (7.7 ± 1.5 ms) compared with the supraspinatus muscle. These results demonstrate that the methods of the present study would be valid for shoulder exercises with lighter weights. However, further investigation is needed to identify the exact relationship between the muscle used and the weight load used for exercises.

The increase in relaxation time for the supraspinatus muscle after the empty can exercise was not significantly different from that after the full can exercise. This indicates that the supraspinatus muscle was used equally for the full can and empty can exercises. According to Otis et al.,[30] the abductor moment-arm length of the anterior part of the supraspinatus muscle is increased by movement of the humerus from an internally to an externally rotated position, while that of the posterior part of the supraspinatus muscle is decreased. Accordingly, the abductor moment-arm length of the entire supraspinatus tendon would not appear to be significantly different between externally and internally rotated positions. Matsen et al.[28] also demonstrated that the rotator cuff fibers bend at their insertion, that is, at the level of the fibrocartilage, as the humerus is moved from internal rotation to external rotation. This indicates that the tendon itself remains parallel to the spine of the scapula and superior to the humeral head during humeral rotation, and that the rotational position of the humeral head does not significantly influence force production of the supraspinatus muscle during shoulder abduction in the scapular plane. Increases in T2 relaxation time for the other rotator cuff muscles after the empty can and full can exercises also did not differ significantly. Only the posterior portion of the deltoid muscle was used more in performing the empty can exercise than the full can exercise.

In conclusion, the present study demonstrates that the horizontal abduction exercise is less effective for strengthening the supraspinatus muscle than the empty can and full can exercises. Because we found no significant differences in loading of the supraspinatus muscle between the empty can and full can exercises, full can exercises can be used for rehabilitation as well as the empty can exercise.

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