Four-Week Exercise Program Does Not Change Rotator Cuff Muscle Activation and Scapular Kinematics in Healthy Subjects

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ABSTRACT: Rotator cuff and scapular muscle strengthening exercises are an essential part of shoulder rehabilitation and sports training. Although the effect of exercise training on pain and function have been widely investigated, few studies have focused on the changes in shoulder kinematics and muscle activity after exercise training. Therefore, the purpose of the present study was to investigate the effect of rotator cuff and scapular strengthening exercises on shoulder kinematics and the activation of rotator cuff and scapular muscles in healthy subjects. Thirty-six healthy subjects were recruited and randomly assigned into either a training or control group. Subjects in the training group were trained with rotator cuff and scapular strengthening exercises for 4 weeks. Scapular kinematics and shoulder muscle activity during arm elevation were measured before and after exercise training. After the 4-week training protocol, there was an increase in strength and a decrease in upper trapezius activation in the training group, which is consistent with previous studies. However, no difference was found in scapular kinematics and activation of rotator cuff muscles between the control and training groups after the training protocol. Although the exercise protocol resulted in strength gains for the rotator cuff, these gains did not transfer to an increase in muscle activation during motion. These results demonstrate the difficulty in changing activation patterns of the rotator cuff muscles. © 2016 Orthopaedic Research Society. Published by Wiley Periodicals, Inc. J Orthop Res

Keywords: scapula; electromyography; kinematics; rotator cuff; strengthening exercise

Dynamic control of the humeral and scapular muscles plays an important role in stabilizing the shoulder.[1] During arm elevation, the rotator cuff muscles counterbalance the upward shear force from the deltoid by producing compressive and inferior forces in order to center the humeral head in the glenoid fossa.[2] If the rotator cuff force is insufficient, the deltoid superior shear forces could result in excessive superior translation of the humeral head, which has been demonstrated in cadaver,[3] fatigue,[4] and nerve block models.[5] The excessive superior translation of the humerus may result in the impingement of subacromial tissues, which is often referred to as shoulder impingement syndrome.[6]

Motion of the humerus in space is the result of synchronous motion of the glenohumeral and scapulothoracic articulations. Investigators have found that motion of the scapula is three dimensional, demonstrating posterior tilting, upward rotation, and external rotation during arm elevation.[7,8] This motion of the scapula moves the acromion away from the humeral head to prevent impingement of the subacromial tissue and also orients the glenoid fossa for optimal contact of the humeral head.[9] Scapular movement is mainly controlled by the trapezius and serratus anterior muscles, which coordinate the movement of the scapula on the thoracic rib cage.[1,10] Altered scapular kinematics during arm elevation, including insufficient scapular upward rotation and posterior tilt, is associated with shoulder impingement syndrome.[8,10] An increase in upper trapezius activity and a decrease in lower trapezius and serratus anterior activity during shoulder movement has also been demonstrated in patients with shoulder impingement syndrome.[10,11]

Because of the essential roles played by the rotator cuff and scapular muscles in shoulder stability, exercises to strengthen these muscles are recommended for shoulder injuries or sports training.[12,13] These exercises are performed with shoulder movements in which the rotator cuff and scapulothoracic muscles show high muscle activity. It also has been emphasized that the movements should elicit high activity levels of the rotator cuff and scapulothoracic muscles, along with low activation levels of the deltoid, upper trapezius, or pectoralis major.[14–17] These exercises are thought to strengthen the rotator cuff, lower trapezius, and serratus anterior muscles and ultimately improve the contribution of these muscles during functional movements.[14–17] However, most studies assessing electromyography (EMG) only measured muscle activation during the exercises,[14–17] and studies investigating exercise training effect mainly focused on improvements in pain and functional outcomes.[18–21] Only a few studies have examined whether muscle activation and movement patterns during functional shoulder movements change after training or treatment, which is the rationale behind the exercises. Although in general, exercises lead to an increase of shoulder muscles strength,[22–24] there are no reported changes in scapular kinematics after exercise training.[23,25] Only one study has investigated scapulothoracic muscle activation during movements after exercise, and that study showed that the ratio of upper trapezius to serratus anterior activity decreased after training.[26] It is currently unknown whether rotator cuff and scapulothoracic muscle strengthening exercises result in neuromuscular adaptations during dynamic movement.

Therefore, the purpose of this study was to investigate the effect of exercise on shoulder kinematics and

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muscle activity in a healthy population. We hypothesized that after strength training of the rotator cuff and scapulothoracic muscles, the activation of the rotator cuff, lower trapezius, and serratus anterior muscles would increase during arm elevation while the activation of the deltoid and upper trapezius would decrease during arm elevation.

METHODS

Subjects

Thirty-six healthy subjects were recruited from the University of Oregon. Subject exclusion criteria for the study were as follows: (i) prior shoulder and cervical surgery; (ii) presence of shoulder and neck pain and injuries; (iii) history of cervical or shoulder pain or pathology in past 3 years; (iv) a concussion within the past 12 months or a history of three or more concussions; (v) brain injury and neurological impairment; (vi) history of seizures; (vii) taking anti-seizure and anti-depressive medication; (viii) pacemaker and other magnetic implant; (ix) pregnancy; and (x) participation on a NCAA sports team. Questions of the history and symptoms listed in the exclusion criteria were asked during the screening procedure. During the testing procedure, (e.g., maximum voluntary contraction measures [MVC] and elevation tasks), motion patterns were observed and subjects were asked if there was any discomfort or pain in order to ensure the health status of their shoulders. Two subjects, who were assigned into the training group, demonstrated mild winging of scapula during arm elevation task but no shoulder pain or discomfort were report by all subjects. These two subjects were still included in the analysis. The study was approved by the Office for Protection of Human Subjects at the University of Oregon and all subjects signed an informed consent form.

Procedure

The study was a randomized controlled trial (level 1) in a healthy population. Subjects were randomly assigned into either a control or training group during their first visit to the lab. The age, height, and weight of subjects in both groups were similar, with no significant between-group difference (Table 1). Shoulder kinematics and EMG of the dominant arm were assessed at baseline and 4–5 weeks later for both groups. For the control subjects, these were the only two visits to the lab and they were asked to maintain their normal activity level between visits. For the subjects in the training group, between these two visits for shoulder kinematics and EMG measurements, there were two additional visits for exercise intensity evaluation, and 12 visits for exercise training. Intensity evaluation, 10 repetition maximum (RM), was assessed before the start of exercise training and between the sixth and seventh visits.

Table 1. Subject Characteristics: Means (Standard Deviations)

	Training ($n = 18$)	Control ($n = 18$)	p
Age (y)	20.3 (1.9)	21.1 (3.9)	0.42
Height (cm)	167 (10)	168 (10)	0.77
Weight (kg)	67.3 (12.3)	65.8 (14.0)	0.73
Sex	9M, 9F	8M, 10F	
Dominant side	16R, 2L	16R, 2L	

M, male; F, female. R, right-hand dominant; L, left-hand dominant. Independent t-test was used to examine the difference between groups.

Kinematics

A magnetic tracking device (Polhemus Liberty, Colchester, VT) was used to measure thoracic, scapular, and humeral kinematics with a sampling rate of 120 Hz. A transmitter, three sensors, and a digitizer of the tracking device were used. The sensors were mounted on the manubrium of the sternum, the flat area of the acromion, as well as on the distal humerus via a custom-molded Orthoplast™ cuff and Velcro™ strap.[10] The transmitter was positioned posterior and contralateral to the testing arm of the subject. The subject sat on an ergonomically designed kneeling chair (Better Posture Kneeling Chairs, Jobri®, Konawa, OK) (Fig. 1).

Anatomic landmarks were palpated and digitized, using the standards recommended by the International Society of Biomechanics (ISB).[27] The thoracic anatomic coordinate system was derived from T8, C7, the xiphoid process, and the jugular notch. The digitization points for the scapula were the root of the scapular spine, inferior angle of the scapula, and laterodorsal point of the acromion. The humeral coordinate system was defined with the second option in the ISB proposed standard, which includes the center of the humeral head, medial epicondyle, lateral epicondyle, ulnar styloid process, and medial styloid process.[27] The center of the humeral head was calculated using a least squares algorithm and was defined as the point that moved the least during several small arcs of motion.[28]

After the digitization and calibration process, the kinematic data were converted from sensor coordinate systems to anatomic coordinate systems and humerothoracic and scapulothoracic motions were calculated. Based on the ISB standard, for humerothoracic motion, the following Euler sequence was used: Plane of elevation, elevation, and axial rotation. For scapulothoracic motion, the Euler sequence was posterior/anterior tilting, upward/downward rotation, and internal/external rotation.[27]

EMG

A Myopac Jr (Run Technologies, Mission Viejo, CA) was used to collect raw EMG data of the middle deltoid, supraspinatus, infraspinatus, upper trapezius, lower trapezius, and serratus anterior. This unit provided signal amplification, band pass

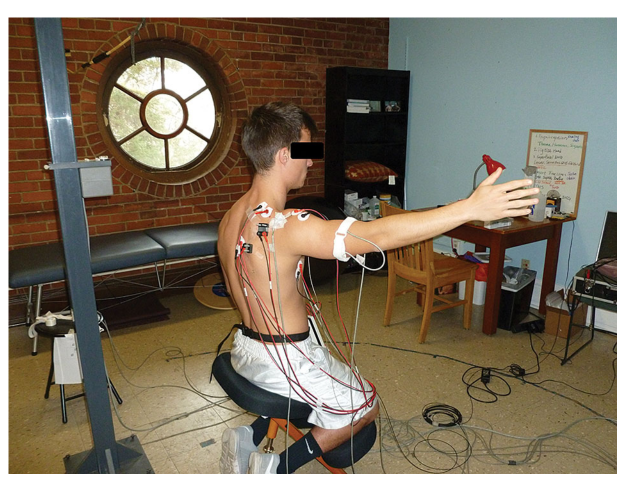

Figure 1. Testing position and sensor placement.

filtering (10–1,000 Hz), and a common mode rejection ratio of 110 dB. Output from the Myopac was linked to an analog to digital board and data were sampled at 1,000 Hz.

Customized fine-wire electrodes were used for the supraspinatus and infraspinatus. The fine-wire electrodes were prepared with a two-inch, 25 Gage hypodermic needle (Covidien/Kendall Monoject™ hypodermic needle, Minneapolis, MN) and four 22 cm long wires. The wires were 200 μm diameter, Stablohm 800, annealed, and HPN-green insulation (California Fine Wire Company, Grover Beach, CA). The four wires were spun and twisted together and different length of hooks were formed at the tips of the wires. The green insulation of the tips of the hooks was removed for recording, but only two of the four wires were used to record EMG activity. The other two hooks of the wires helped anchor the electrodes in the muscles. For the supraspinatus, the electrodes were inserted at 2.5 cm above the midpoint of the scapular spine and to the bottom of the supraspinous fossa.[29] For the infraspinatus, the fine-wire electrodes were inserted at the midpoint of the inferior angle of scapula and the midpoint of scapular spine and inserted to the bottom of infraspinous fossa.[30] To confirm the fine-wire stayed in the supraspinatus, muscle contractions of the upper trapezius and supraspinatus during shoulder shrug and abduction with the arm at the side were tested, both before and after arm elevation trials.

The middle deltoid, upper trapezius, lower trapezius, and serratus anterior were measured with surface EMG electrodes (Bio-protech Inc, Wonju si, Gangwon-do, Korea). The electrodes of the middle deltoid were placed at the lateral aspect of the arm approximately 3 cm below the acromion for the middle deltoid.[31] The electrodes for the upper trapezius were attached to the midpoint of the acromion and C7.[32] The electrodes of the lower trapezius were placed at the midpoint of the root of the scapular spine and T7.[32] For the serratus anterior, the electrodes were attached on the midaxillary line and in front of latissimus dorsi when the arm was flexed at 90°.[10]

Forces and EMG of MVC

The force and EMG of a five second MVC were measured simultaneously prior to EMG assessment. Four specific testing positions were conducted to measure the MVC of the six muscles, with three trials for each testing position. There was a 30 s rest between trials and 1 min of rest between positions. A handheld dynamometer micro FET2 (Hoggan Scientific, Salt lake city, UT) was used to measure forces during MVC, except for elevation at 90°. The handheld dynamometer was positioned at the wrist joint. The infraspinatus MVC was tested by resisted external rotation with the arm at the side and 90° of elbow flexion.[33] The lower trapezius MVC was tested in a prone position with horizontal abduction in 120° of elevation in line with the fibers of the lower trapezius and the thumb pointing upward.[34] For the serratus anterior, the MVC was measured with 135° of abduction in the scapular plane.[34]

The MVC of the middle deltoid, supraspinatus, and upper trapezius was measured with abduction in the scapular plane at 90° of humeral elevation with neutral axial rotation.[10,15] In order to provide stable resistance, a load cell (Lebow, Troy, MI) mounted on the wall was used, instead of the handheld dynamometer. The wrist was placed beneath the load cell and the elevation force was measured simultaneously with the EMG of these three muscles.

The EMG amplitude of the MVC was calculated by taking the root mean square (rms) of the middle 1.5 s of the muscle contraction. The maximum rms of the trials was used for normalization. For the force measured by the load cell, the force was calculated by the mean of the middle 1.5 s of the muscle contraction. The dynamometer recorded the peak force of the muscle contraction. The MVC force measures were averaged across three trials.

Testing Protocol

After MVC testing, the subjects were instructed to perform three arm elevation trials in the scapular plane. To maintain humeral elevation in the scapular plane, subjects were asked to point their hand to a pole 1.5 m away or a target they found on the wall. The speed of the movement was controlled by a metronome, with each elevation trial performed for 8 s, 4-s ascending and 4-s descending. The subject was allowed to practice for three to five trials to help become familiarized with the motion. A customized LabVIEW program (Version 2012, National Instruments, Austin, TX) was used to simultaneously collect and synchronize shoulder kinematics and EMG data during arm elevation.

Exercise Training

The subjects in the control group were instructed to maintain their normal activities of daily living while the subjects in the training group were trained three times per week for 4 weeks with an average duration of 30 min per session. All training sections were supervised to ensure compliance with the training protocol. The training protocol included strengthening and neuromuscular exercises targeting the rotator cuff and scapulothoracic muscles. The order of the exercises was randomized at each visit.

The strengthening exercises included full can, sidelying external rotation, diagonal exercise, and prone full can at 100° of abduction (Fig. 2; Table 2). These exercises were chosen because they specifically generate higher level of activation of the rotator cuff, lower trapezius, or serratus anterior.[13,15] The exercise intensity, 10 RM, was tested before the first visit of the exercise training and measured again in the third week, before the seventh training section. The strengthening training consisted of three sets of 10 repetitions using variable resistance: One set at 50% of the 10 RM, one at 75% of the 10 RM, and one at 100% of the 10 RM.[24] Sand bags with different weights and adjustable dumbbells were used in the exercise training. If the training resistance was below 2.2 kg, a sand bag was wrapped around the wrist to provide the resistance. For resistance above 2.2 kg, an adjustable dumbbell was used and was held in the hand of the subject. For the diagonal exercise, a bag containing sand bags or discs of dumbbells was hooked at the other end of the pulley system to provide the resistance.

The neuromuscular training consisted of upper extremity weight-bearing exercises: Push-up with plus and balance exercise. These exercises were believed to facilitate the co-contraction of shoulder muscles[35,36] as well as strengthen the serratus anterior.[12,13] For the push-up with plus, the subjects were instructed to push up and protract their shoulder with a straight elbow for 15–40 repetitions, depending on the ability of the subject. If the subjects were not able to perform a regular push-up, they started in a quadruped position and then progressed to the push-up on toes (Fig. 2e). For the balance exercise, subjects maintained the push-up position with their hands on an exercise ball or a wobble

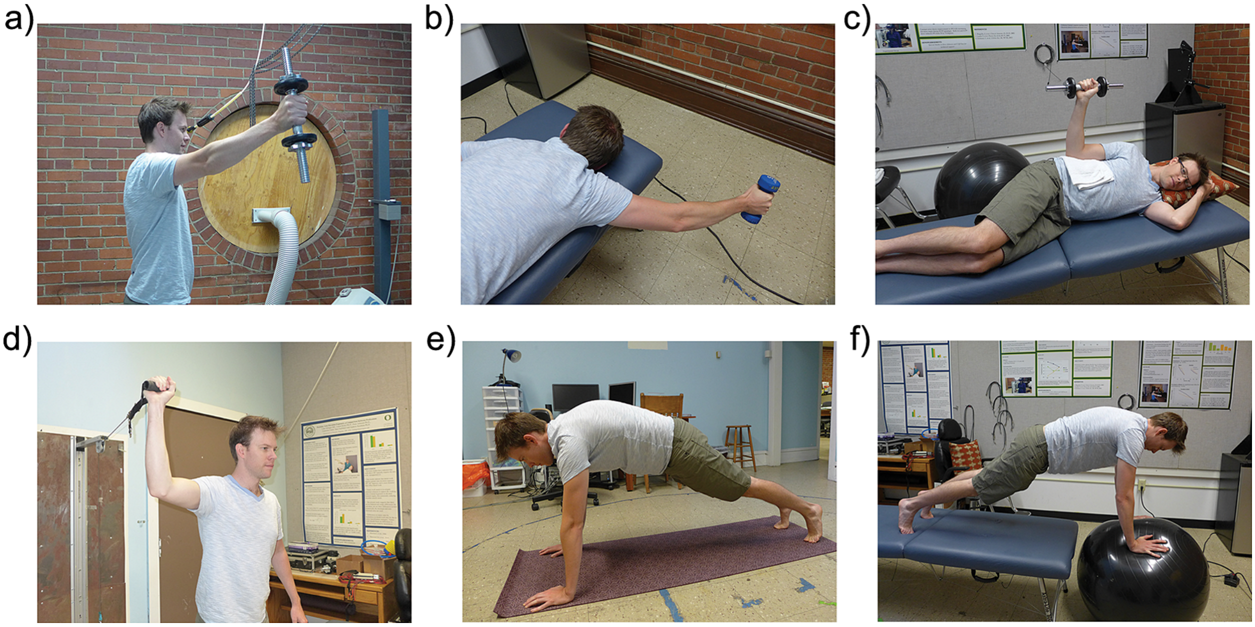

Figure 2. Exercises for the rotator cuff and scapulothoracic muscles: (a) full can; (b) prone full can; (c) sidelying external rotation; (d) diagonal exercise; (e) push up with plus; and (f) balance exercise.

board for five repetitions with 15 s for each repetition. A wobble board was used if the subject was unable to maintain their position on the ball. The balance exercise progressed from a quadruped position to a push-up on the toes to a one-arm push-up (Fig. 2f).[24] The interval between sets was 1 min. There was a rest period of 3 min between each exercise.

The subjects in the training group were asked to do home exercises, including full can, bilateral external rotation with the arm at the side in standing, and push up with plus. A resistance band (TheraBand, the Hygenic Corporation, Akron, OH) was used to provide resistance of the full can and bilateral external rotation. Blue resistance bands were assigned to all male subjects. Red resistance bands were assigned to all female subjects except one female subject, whose exercise intensity was close to that of the male subjects. Therefore, this female subject used a blue resistance band. The subjects were taught to adjust the length of the band, so they could feel the resistance during the home exercise but still could perform the exercise with full range of motion and assigned repetition. The subjects were asked to perform each exercise 10 repetitions a day every day for the first 2 weeks (even on days when they had exercise training). The repetition of each exercise increased to 20 repetitions a day for the last 2 weeks.

Table 2. Exercises for 4-Week Exercise Training

Exercise	Target	Reference
Full can	Supra	Reinold et al.[15]
Prone full can	Supra, infra, LT	Reinold et al.[15]; Cools et al.[51]
Sidelying ER	Infra, LT	Reinold et al.[14]; Cools et al.[51]
Diagonal EX	Sub, LT, SA, TM	Decker et al.[16]; Myers et al.[52]
Push-up with plus	Sub, SA, proprioception	Decker et al.[16]; Ludewig et al.[53]; Rogol et al.[54]
Balance EX	Shoulder stability Cocontraction	Ubinger et al.[36]

ER, external rotation; EX, exercise; Supra, supraspinatus; infra, infraspinatus; sub, subscapularis; TM, teres minor; LT, lower trapezius; SA, serratus anterior.

Data Reduction

For force measures, the percentage change was calculated, which is the force change from the pre- to post-training divided by the force at the pre-training. For scapular kinematics, anterior/posterior tilt, upward/downward rotation, and internal/external rotation at 30°, 60°, 90°, and 120° were calculated.[10] Because we observed that the EMG data were contaminated by electrocardiogram (ECG), especially the data of the serratus anterior, a filter based on independent component analysis was used to remove electrocardiogram contamination.[37] The root mean square of EMG data were normalized by the MVC amplitude and calculated over three 30° increments of motion during arm elevation from 30° to 120°, including 30–60°, 60–90°, and 90–120°.[38]

Statistical Analysis

A three-way, mixed-effects analysis of variance (ANOVA) was used to examine the effect of exercise on shoulder kinematics. Angle (30°, 60°, 90°, and 120°) and time (pre- and post-training) were the within subject effect. The between-subject effect was group (control and training groups).

For shoulder EMG, because we were concerned with differences in pre-training EMG between groups, a two-way ANCOVA was run to test the difference of the post-training EMG between groups. The pre-training EMG amplitudes at different levels of elevation were averaged for each muscle and the averaged pre-training EMG amplitude was used as covariance. The dependent variable was the EMG of the post-training test. The within-subject effect was angle range, including 30–60°, 60–90°, and 90–120°. The between-subject effect was group (control and training groups). When there was an interaction effect, pairwise comparisons were conducted to examine the difference between groups.

An independent t-test was used to examine the difference of the percentage changes in the MVC forces between groups. The significant level was set at 0.05 for all analyses.

RESULTS

All the subjects in the control group completed two shoulder kinematics and EMG assessments. One subject in the training group did not finish the exercise training and the second shoulder kinematics and EMG assessment due to personal reasons. All other subjects in the training group completed all the training sections and two assessments. In one subject in the control group and one in the training group, it was found that the fine-wire electrodes of the supraspinatus had likely slid into the upper trapezius in the post-training test. This assertion was based on the comparison of the supraspinatus EMG between the two testing contractions: Shoulder shrug and abduction with arm at the side. The data of these subject were not included in the analysis. It resulted in 17 subjects in the control group and 16 subjects in the training group in data analysis.

Percentage changes of MVC forces during elevation at 90°, external rotation with the arm at the side, and horizontal abduction in 120° of elevation was significantly different between groups ($p = 0.022$, 0.046, and 0.015, respectively). There was a 6–20% increase in the training group and the changes of −5% to 7% in the control group. No difference between groups was found in the force of 135°of elevation ($p = 0.914$) (Fig. 3).

For scapular kinematics (anterior/posterior tilt, upward/downward rotation, internal/external rotation), the three-way ANOVA showed that although there was a significant angle effect ($p < 0.05$), there was no significant difference in group effect, three-way interaction (angle × time × group) or two-way interaction of group and time, angle and group, and time and angle ($p > 0.05$) (Fig. 4).

For the EMG measures, the ANCOVA showed there was no significant interaction effect of group and angle, group effect, and angle effect in the deltoid, supraspinatus, and infraspinatus ($p > 0.05$) (Fig. 5). There was an angle effect ($p = 0.022$) and there was a group difference in the upper trapezius EMG after 4 weeks ($p = 0.004$) with no interaction of angle and group ($p = 0.158$). The group effect of the serratus anterior after 4 weeks was close to significance ($p = 0.056$) with no interaction effect ($p = 0.142$) and no angle effect ($p = 0.569$). There was an angle effect of the lower trapezius ($p = 0.003$) but there was no interaction of angle and group ($p = 0.656$), and no group effect ($p = 0.446$) (Fig. 6).

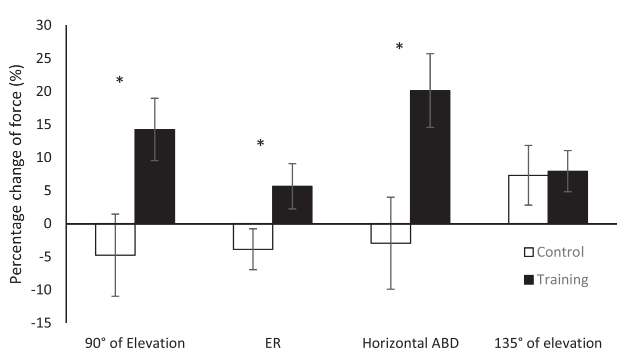

Figure 3. Percentage changes of the forces from pre-training to post-training in the control and training groups. The maximum voluntary contraction (MVC) forces of the deltoid, supraspinatus and upper trapezius were measured with 90° of elevation in the scapular plane with neutral axial rotation. The infraspinatus MVC force was tested by resisted external rotation (ER) with the arm at the side. The lower trapezius MVC was tested in a prone position with horizontal abduction (ABD) in 120° of elevation. The serratus anterior MVC was measured with 135° of elevation in the scapular plane.

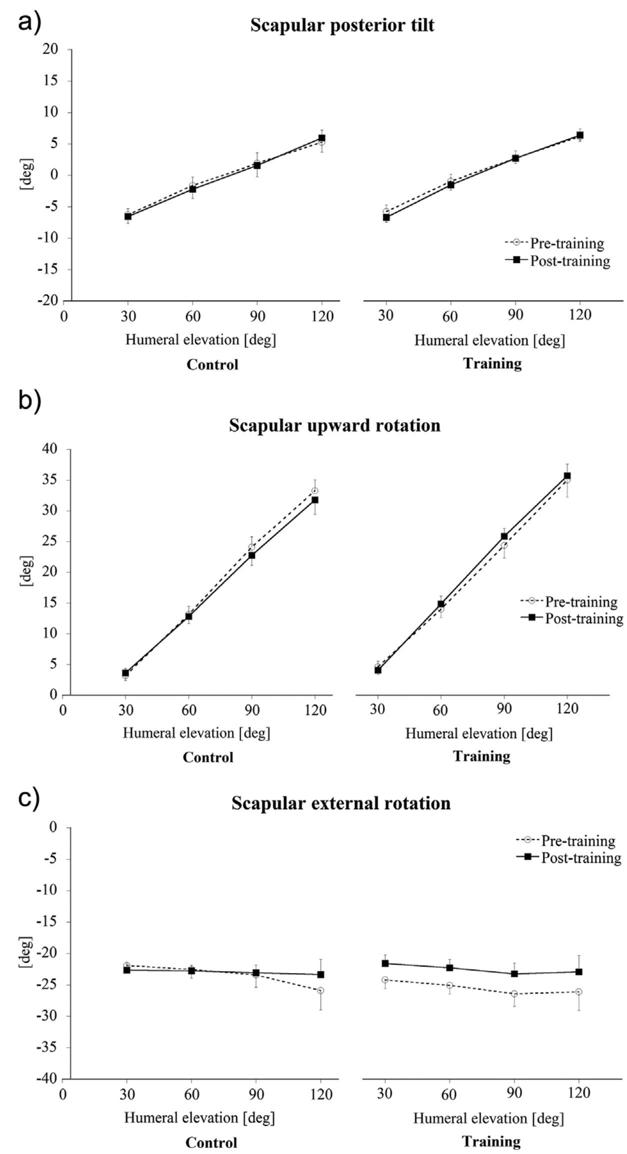

Figure 4. Scapular kinematics of pre-training and post-training conditions in the control and training groups: (a) scapular anterior/posterior tilt; (b) upward/downward rotation; (c) internal/external rotation.

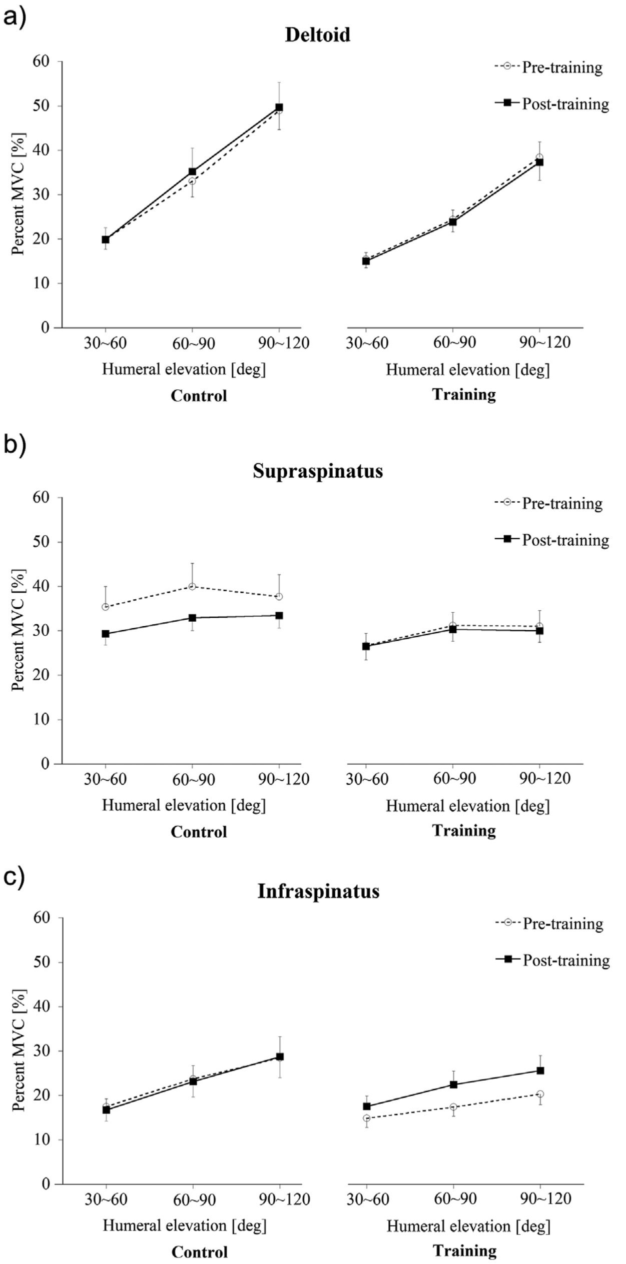

Figure 5. Muscle activation of the deltoid and rotator cuff muscles of pre-training and post-training conditions in the control and training groups: (a) deltoid; (b) supraspinatus; and (c) infraspinatus. MVC, maximum voluntary contraction.

DISCUSSION

Strengthening and neuromuscular control training for the rotator cuff and scapulothoracic muscles is an essential part of shoulder rehabilitation. Although many studies have investigated which exercises induced high EMG of rotator cuff and scapulothoracic muscles during the exercise,[13,15] only a few studies examined the effect of the exercises on the shoulder kinematics and EMG.[23,25,26] Therefore, in the present study, healthy young subjects were trained with strengthening and neuromuscular control exercises for rotator cuff and scapulothoracic muscles over a 4-week period. By comparison with the subjects in the control group, the subjects in the training group demonstrated significant increases in three out of four force measures, significant decrease in EMG of upper trapezius, and a trend of increasing EMG of the serratus anterior, while there was no difference in scapular kinematics and the EMG of the deltoid and rotator cuff muscles.

For the glenohumeral joint, the rotator cuff muscles play the dominant role in stabilizing the joint, by providing compressive forces that pull the humeral head into the glenoid fossa and downward forces that counterbalance the deltoid upward shear force.[2] In the present study, we included full can, prone full can, and sidelying external rotation exercises to strengthen the supraspinatus and infraspinatus muscles, as well as closed-chain exercise for facilitating co-contraction. We hypothesize that after the exercise training, the muscle activation level of the rotator cuff would increase during arm elevation, which increases the stability of the glenohumeral. Although the forces during elevation and external rotation at the side significantly increased, compared to that of the control subjects, the activation of the supraspinatus and infraspinatus during arm elevation did not change after training. The supraspinatus and infraspinatus are stabilizers of the glenohumeral joint and also serve as abductors and external rotators.[39] We selected exercises to train the supraspinatus and infraspinatus to become stronger abductors and external rotators and also used closed-chain exercises to induce co-contraction of all the muscles around the shoulder. However, the training effect did not transfer to their roles as stabilizers during open-chain arm movements. In other words, the supraspinatus and infraspinatus did not contribute more during arm elevation, even though they become stronger. This result may demonstrate the activation pattern of the rotator cuff are already optimized in healthy subjects, so it is difficult to change the activation pattern in healthy subjects. Therefore, to train the neuromuscular control in healthy population, advance exercises, such as plyometric exercises and more closed-chain exercises, may need to include in a training protocol. Moreover, the present study is the first study investigating the muscle activation of the rotator cuff muscles after exercise. Future work should also examine the effect of exercises in the subjects with shoulder injuries. Because exercise reduces pain and increases strength of weak muscles,[23] the activation of rotator cuff muscles may change with the removal of pain inhibition.

Patients with shoulder impingement syndrome demonstrate greater upper trapezius activation and less lower trapezius and serratus anterior activation.[10,11,40] Greater upper trapezius activation is believed to compensate for less serratus anterior activation because serratus anterior substantially produce scapular upward rotation and posterior tilt.[1,41] We found after a 4-week exercise training program, the activity of the upper trapezius decreased significantly and there was a trend of increasing serratus

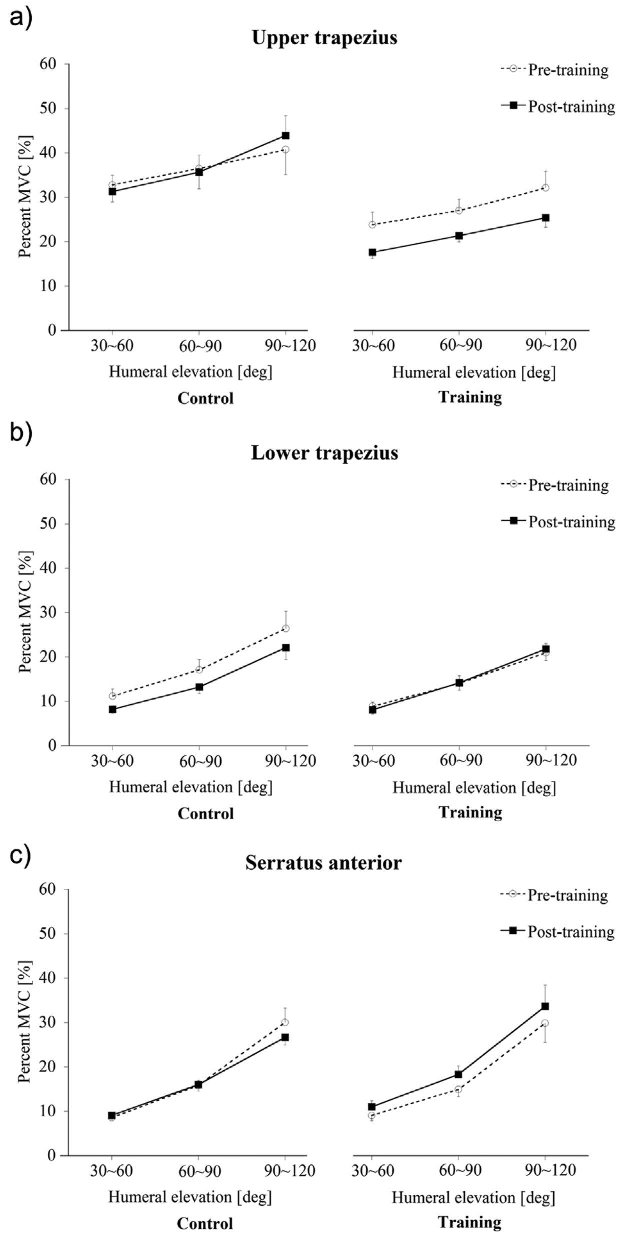

Figure 6. Muscle activation of the scapulothoracic muscles of pre-training and post-training conditions in the control and training groups: (a) upper trapezius; (b) lower trapezius; and (c) serratus anterior. MVC, maximum voluntary contraction.

anterior activity throughout arm elevation. This is similar to the findings of De Mey et al.[26] They found the activity of the upper trapezius decreased during arm elevation with a decreased ratio of upper trapezius activation to serratus anterior activation after a 6-week scapular muscle rehabilitation for overhead athletes with shoulder impingement syndrome. Therefore, shoulder strengthening exercises not only decrease pain and improve function but also can also change the activation patterns of the scapulothoracic muscles. The activation patterns of scapulothoracic muscles, less upper trapezius, and greater serratus anterior activation, during the exercise training can be transferred to functional shoulder movement, such as arm elevation in this present study.

Altered scapular kinematics is one of the identified factors contributing to shoulder impingement syndrome,[42] and has been found in subjects with shoulder impingement syndrome,[10,43,44] especially in the patients with visible scapular dyskinesis.[8,45] The altered scapular kinematics in subjects with shoulder impingement syndrome includes less scapular upward rotation and external rotation.[46] Exercises are thought to restore normal shoulder kinematics by increasing upward rotation and external rotation. However, in healthy subjects, although strengthening exercises changed the coordination of the scapulothoracic muscle activity, the changes of the patterns of scapulothoracic activation did not alter shoulder kinematics. Since other factors contribute to scapular kinematics in addition to scapulothoracic muscle activation, such as length of pectoralis minor muscle[47] and posture,[48] the changes of the scapulothoracic muscle activation may not be sufficient to change the scapular kinematics. In previous studies, exercise also failed to change the scapular kinematics to being more upwardly rotated and externally rotated during shoulder movement. Wang et al. trained healthy subjects with strengthening exercise for scapular retractors and elevators as well as shoulder abductors and external rotators, and found that the scapula showed less upward rotation and less superior translation at 90° of shoulder abduction, although strength increased after 6-week exercise training.[22] The difference in the effect of exercise between the present study and the study of Wang et al. may be due to different exercise training and different assessments of kinematics.

Other studies also showed no effect of shoulder rehabilitation or strengthening exercise on scapular kinematics in patients with shoulder impingement syndrome[23] or overhead athletes.[25] However, Worsley et al. included motor control retraining of the scapula for subjects with shoulder impingement syndrome and found scapular upward rotation and posterior tilt increased significantly after a 10-week treatment.[49] Therefore, in addition to stretching and strengthening exercises, training for controlling or being aware of scapular position may be necessary for patients with shoulder dyskinesis.

There are some limitations in the present study that must be addressed. The first is that since the population of subjects in the present study was young and healthy, the results may not be generalized to an older or injured population. The muscle activation and kinematics are considered normal, so it may be difficulty to change. Moreover, although we noticed two subjects demonstrated mild winging of scapula during arm elevation, they were still included because no symptom or pain was reported. Although we recorded specific muscle activation during MVC measurement, the MVC forces only represent the general force in the directions of contractions, instead of the forces of specific muscles. The force changes in synergist muscles may confound our measurements. This is especially true when the force of horizontal abduction in 120° of elevation was measured, since the resistance was applied on the wrist. The muscles around the glenohumeral joint, such as the posterior deltoid, may also influence the force measures. Although the placement of the resistance could have been applied on scapular spine,[50] it is not clear that this would be a valid assessment of lower trapezius force levels. Because the exercises targeted specific muscles, we used the exercise intensity of 50%, 75%, and 100% of 10 RM during exercise training. Although the muscle forces increased after the exercise training, the intensity may not be sufficient to change the muscle activation of the rotator cuff muscles. The sample size of the present study was not sufficient to categorize subjects into subgroups. The effect of exercise on healthy subjects with mild dyskinesis may need further investigation. Some of the subjects complained of discomfort and mild pain (2–3 in numeric rating scale) during the arm elevation trials, due to the fine-wire electrodes. This could have influenced muscle activation patterns. In addition, we normalized the EMG data to a maximum contraction. However, since the force of the MVC increased after exercise training, our results should only be interpreted as a change with respect to the maximum capacity of the muscle. No conclusions can be drawn with respect to the absolute force level of the muscle. The duration of the exercise was 4 weeks, which may not be sufficient to induce neuromuscular changes for kinematics and rotator cuff EMG patterns. Future work may be needed to investigate the effect of an exercise protocol that is longer than 4 weeks and correlate the changes in muscle activation with other measures, such as shoulder kinematics, pain, and functional outcomes. The muscle activation level of rotator cuff muscles may increase if the training duration is more than 4 weeks. Finally, we did not measure the subscapularis, since shoulder injuries affect the supraspinatus and infraspinatus more frequently.

CONCLUSION

After a 4-week training protocol focusing on shoulder strengthening and neuromuscular control, strength was increased overall. However, with a decrease in EMG activity, the upper trapezius was the only muscle that demonstrated a change in activation during motion (there was a trend of an increase for the serratus anterior). Of particular interest is that while the exercise succeeded in increasing rotator cuff strength, these gains did not transfer to an increase in muscle activation during motion. Thus, the benefits of this exercise program on glenohumeral joint stability are questionable in healthy subjects. Additionally, there were no changes in scapular kinematics after the exercise protocol, demonstrating the difficulty in changing this movement pattern in healthy subjects. Future work should focus on the effects of exercise in the subjects with shoulder injuries.

AUTHORS' CONTRIBUTIONS

Yin-Liang Lin designed the study, conducted data acquisition, interpreted the data, and drafted the paper. Andrew Karduna contributed to study design, data interpretation, manuscript revision, and approval of the submitted and final versions of the paper. Both authors have read and approved the final submitted manuscript.

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REFERENCES

1. Ludewig PM, Reynolds JF. 2009. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 39:90–104.
2. Halder AM, Zhao KD, O'Driscoll SW, et al. 2001. Dynamic contributions to superior shoulder stability. J Orthop Res 19:206–212.
3. Sharkey NA, Marder RA. 1995. The rotator cuff opposes superior translation of the humeral head. Am J Sports Med 23:270–275.
4. Chen S-K, Simonian PT, Wickiewicz TL, et al. 1999. Radiographic evaluation of glenohumeral kinematics: a muscle fatigue model. J Shoulder Elbow Surg 8:49–52.
5. San Juan JG, Kosek P, Karduna AR. 2013. Humeral head translation after a suprascapular nerve block. J Appl Biomech 29:371–379.
6. Yamaguchi K, Sher JS, Andersen WK, et al. 2000. Glenohumeral motion in patients with rotator cuff tears: a comparison of asymptomatic and symptomatic shoulders. J Shoulder Elbow Surg 9:6–11.
7. Karduna AR, McClure PW, Michener LA. 2000. Scapular kinematics: effects of altering the Euler angle sequence of rotations. J Biomech 33:1063–1068.
8. Lawrence RL, Braman JP, Laprade RF, et al. 2014. Comparison of 3-dimensional shoulder complex kinematics in individuals with and without shoulder pain, Part 1: sternoclavicular, acromioclavicular, and scapulothoracic joints. J Orthop Sports Phys Ther 44:636–645, A631–638.
9. Kibler WB. 1998. The role of the scapula in athletic shoulder function. Am J Sports Med 26:325–337.
10. Ludewig PM, Cook TM. 2000. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 80:276–291.
11. Lin J-J, Hsieh S-C, Cheng W-C, et al. 2011. Adaptive patterns of movement during arm elevation test in patients with shoulder impingement syndrome. J Orthop Res 29: 653–657.
12. Cricchio M, Frazer C. 2011. Scapulothoracic and scapulohumeral exercises: a narrative review of electromyographic studies. J Hand Ther 24:322–334.
13. Reinold MM, Escamilla RF, Wilk KE. 2009. Current concepts in the scientific and clinical rationale behind exercises for glenohumeral and scapulothoracic musculature. J Orthop Sports Phys Ther 39:105–117.
14. Reinold MM, Wilk KE, Fleisig GS, et al. 2004. Electromyographic analysis of the rotator cuff and deltoid musculature

during common shoulder external rotation exercises. J Orthop Sports Phys Ther 34:385–394.
15. Reinold MM, Macrina LC, Wilk KE, et al. 2007. Electromyographic analysis of the supraspinatus and deltoid muscles during 3 common rehabilitation exercises. J Athl Train 42: 464–469.
16. Decker MJ, Tokish JM, Ellis HB, et al. 2003. Subscapularis muscle activity during selected rehabilitation exercises. Am J Sports Med 31:126–134.
17. Ellenbecker TS, Cools A. 2010. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. Br J Sports Med 44:319–327.
18. Bennell K, Wee E, Coburn S, et al. 2010. Efficacy of standardised manual therapy and home exercise programme for chronic rotator cuff disease: randomised placebo controlled trial. BMJ 340:c2756.
19. Brox JI, Staff PH, Ljunggren AE, et al. 1993. Arthroscopic surgery compared with supervised exercises in patients with rotator cuff disease (stage II impingement syndrome). BMJ 307:899–903.
20. Brox JI, Gjengedal E, Uppheim G, et al. 1999. Arthroscopic surgery versus supervised exercises in patients with rotator cuff disease (stage II impingement syndrome): a prospective, randomized, controlled study in 125 patients with a 2 1/2-year follow-up. J Shoulder Elbow Surg 8:102–111.
21. Ludewig PM, Borstad JD. 2003. Effects of a home exercise programme on shoulder pain and functional status in construction workers. Occup Environ Med 60:841–849.
22. Wang CH, McClure P, Pratt NE, et al. 1999. Stretching and strengthening exercises: their effect on three-dimensional scapular kinematics. Arch Phys Med Rehabil 80:923–929.
23. McClure PW, Bialker J, Neff N, et al. 2004. Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program. Phys Ther 84:832–848.
24. Padua DA, Guskiewicz KM, Prentice WE, et al. 2004. The effect of select shoulder exercises on strength, active angle reproduction, single-arm balance, and functional performance. J Sport Rehabil 13:75–95.
25. Hibberd EE, Oyama S, Spang JT, et al. 2012. Effect of a 6-week strengthening program on shoulder and scapular-stabilizer strength and scapular kinematics in division I collegiate swimmers. J Sport Rehabil 21:253–265.
26. De Mey K, Danneels L, Cagnie B, et al. 2012. Scapular muscle rehabilitation exercises in overhead athletes with impingement symptoms: effect of a 6-week training program on muscle recruitment and functional outcome. Am J Sports Med 40:1906–1915.
27. Wu G, van der Helm FC, Veeger HE, et al. 2005. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. J Biomech 38:981–992.
28. Harryman DT 2nd, Sidles JA, Harris SL, et al. 1992. The role of the rotator interval capsule in passive motion and stability of the shoulder. J Bone Joint Surg Am 74: 53–66.
29. Perotto A, Delagi EF, Iazzetti J, et al. 2005. Anatomical guide for the electromyographer: the limbs and trunk. Springfield, IL: Charles C Thomas.
30. Geiringer SR. 1999. Anatomic localization for needle electromyography. Philadelphia, PA: Hanley & Belfus.
31. Cram JR, Kasman GS, Holtz J. 1998. Introduction to surface electromyography. Gaithersburg, Md: Aspen Publishers.
32. Hsu YH, Chen WY, Lin HC, et al. 2009. The effects of taping on scapular kinematics and muscle performance in baseball players with shoulder impingement syndrome. J Electromyogr Kinesiol 19:1092–1099.
33. Alpert SW, Pink MM, Jobe FW, et al. 2000. Electromyographic analysis of deltoid and rotator cuff function under varying loads and speeds. J Shoulder Elbow Surg 9:47–58.
34. Ekstrom RA, Soderberg GL, Donatelli RA. 2005. Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis. J Electromyogr Kinesiol 15:418–428.
35. Myers JB, Oyama S. 2009. Sensorimotor training for shoulder injury: literature review. Athl Train Sports Health Care 1:199–208.
36. Ubinger ME, Prentice WE, Guskiewicz KM. 1999. Effect of closed kinetic chain training on neuromuscular control in the upper extremity. J Sport Rehabil 8:184–194.
37. Willigenburg NW, Daffertshofer A, Kingma I, et al. 2012. Removing ECG contamination from EMG recordings: a comparison of ICA-based and other filtering procedures. J Electromyogr Kinesiol 22:485–493.
38. Reddy AS, Mohr KJ, Pink MM, et al. 2000. Electromyographic analysis of the deltoid and rot tor cuff muscles in persons with subacromial impingement. J Shoulder Elbow Surg 9:519–523.
39. Sangwan S, Green RA, Taylor NF. 2015. Stabilizing characteristics of rotator cuff muscles: a systematic review. Disabil Rehabil 37:1033–1043.
40. Struyf F, Cagnie B, Cools A, et al. 2014. Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability. J Electromyogr Kinesiol 24:277–284.
41. Johnson G, Bogduk N, Nowitzke A, et al. 1994. Anatomy and actions of the trapezius muscle. Clin Biomech 9:44–50.
42. Michener LA, McClure PW, Karduna AR. 2003. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. Clin Biomech 18:369–379.
43. Lukasiewicz AC, McClure P, Michener L, et al. 1999. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. J Orthop Sports Phys Ther 29:574–586.
44. Hebert LJ, Moffet H, McFadyen BJ, et al. 2002. Scapular behavior in shoulder impingement syndrome. Arch Phys Med Rehabil 83:60–69.
45. Lopes AD, Timmons MK, Grover M, et al. 2015. Visual scapular dyskinesis: kinematics and muscle activity alterations in patients with subacromial impingement syndrome. Arch Phys Med Rehabil 96:298–306.
46. Timmons MK, Thigpen CA, Seitz AL, et al. 2012. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. J Sport Rehabil 21:354–370.
47. Borstad JD, Ludewig PM. 2005. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sports Phys Ther 35: 227–238.
48. Finley MA, Lee RY. 2003. Effect of sitting posture on 3-dimensional scapular kinematics measured by skin-mounted electromagnetic tracking sensors. Arch Phys Med Rehabil 84:563–568.
49. Worsley P, Warner M, Mottram S, et al. 2013. Motor control retraining exercises for shoulder impingement: effects on function, muscle activation, and biomechanics in young adults. J Shoulder Elbow Surg 22:e11–e19.
50. Michener LA, Boardman ND, Pidcoe PE, et al. 2005. Scapular muscle tests in subjects with shoulder pain and functional loss: reliability and construct validity. Phys Ther 85:1128–1138.
51. Cools AM, Dewitte V, Lanszweert F, et al. 2007. Rehabilitation of scapular muscle balance: which exercises to prescribe? Am J Sports Med 35:1744–1751.

52. Myers JB, Pasquale MR, Laudner KG, et al. 2005. On-the-field resistance-tubing exercises for throwers: an electromyographic analysis. J Athl Train 40:15–22.
53. Ludewig PM, Hoff MS, Osowski EE, et al. 2004. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. Am J Sports Med 32:484–493.
54. Rogol IM, Ernst G, Perrin DH. 1998. Open and closed kinetic chain exercises improve shoulder joint reposition sense equally in healthy subjects. J Athl Train 33:315.