STEPHANIE MUTH, PT, PhD[1] • **MARY F. BARBE,** PhD[2] • **RICHARD LAUER,** PhD[3] • **PHILIP MCCLURE,** PT, PhD, FAPTA[4]

The Effects of Thoracic Spine Manipulation in Subjects With Signs of Rotator Cuff Tendinopathy

STUDY DESIGN: Controlled laboratory study.

OBJECTIVES: To assess scapular kinematics and electromyographic signal amplitude of the shoulder musculature, before and after thoracic spine manipulation (TSM) in subjects with rotator cuff tendinopathy (RCT). Changes in range of motion, pain, and function were also assessed.

BACKGROUND: There are various treatment techniques for RCT. Recent studies suggest that TSM may be a useful component in the management of pain and dysfunction associated with RCT.

METHODS: Thirty subjects between 18 and 45 years of age, who showed signs of RCT, participated in this study. Changes in scapular kinematics and muscle activity, as well as changes in shoulder pain and function, were assessed pre-TSM and post-TSM using paired *t* tests and repeated-measures analyses of variance.

RESULTS: TSM did not lead to changes in range of motion or scapular kinematics, with the exception of a small decrease in scapular upward rotation (P = .05). The only change in muscle activity was a small but significant increase in middle trapezius activity (P = .03). After TSM, subjects demonstrated decreased pain during performance of the Jobe empty-can (mean ± SD change, 2.6 ± 1.1), Neer (2.6 ± 1.3), and Hawkins-Kennedy (2.8 ± 1.3) tests (all, P<.001). Subjects also reported decreased pain with shoulder flexion (mean ± SD change, 2.0 ± 1.5; P<.001) and improved shoulder function (force production, 2.5 ± 1.4 kg; Penn Shoulder Score, 7.7 ± 9.4; sports/performing arts module of the Disabilities of the Arm, Shoulder and Hand questionnaire, 16.4 ± 13.2) (all, P<.001).

CONCLUSION: Immediate improvements in shoulder pain and function post-TSM are not likely explained by alterations in scapular kinematics or shoulder muscle activity. For people with pain associated with RCT, TSM may be an effective component of their treatment plan to improve pain and function. However, further randomized controlled studies are necessary to better validate this treatment approach.

LEVEL OF EVIDENCE: Therapy, level 4.
J Orthop Sports Phys Ther 2012;42(12):1005-1016. Epub 17 August 2012, doi:10.2519/jospt.2012.4142

KEY WORDS: *joint mobilization, manual therapy, scapula, shoulder impingement*

Rotator cuff tendinopathy (RCT) is one of the most common causes of shoulder pain and dysfunction[5,26,48,73,74] and has been associated with symptoms of shoulder impingement.[15] Symptoms of impingement may result from multiple underlying pathologies, including altered scapular kinematics,[9,44,47,52] glenohumeral posterior shoulder tightness,[42,72] faulty posture,[12,40] acromial arch morphology/pathology,[6,24,63] shoulder instability,[59] rotator cuff weakness, and motor control deficits.[44,51,52,66,67]

Several evidence-based approaches to treat RCT exist, including arthroscopic acromioplasty,[49,56,62] posterior shoulder stretch,[57,72] corticosteroid injection,[25,33,81] strengthening and neuromuscular re-education,[76] and joint mobilization.[1,2,78] The results of multiple randomized controlled trials have indicated that joint mobilization, in addition to therapies such as stretching, strengthening, and neuromuscular re-education, has improved outcomes for people with certain types of shoulder pain.[1,2,78] Two studies have specifically assessed the effects of thoracic spine manipulation (TSM) on pain and dysfunction associated with RCT.[10,69] Both Boyles et al[10] and Strunce et al[69] observed that individuals with shoulder impingement reported immediate decreases in pain and improved function after receiving TSM; however, neither study included a control group for comparison.

While TSM may be beneficial in reducing shoulder pain and dysfunction, the mechanisms by which the manipulation might induce these changes are not well understood. Bialosky et al[3] suggested that the introduction of a manipulative force results in biomechanical as well as neurophysiologic responses. Biomechanical re-

[1]Assistant Professor, Department of Rehabilitation and Movement Sciences, University of Medicine and Dentistry of New Jersey, Stratford, NJ. [2]Professor, Department of Anatomy and Cell Biology, Temple University, Philadelphia, PA. [3]Assistant Professor, Department of Physical Therapy, Temple University, Philadelphia, PA. [4]Professor of Physical Therapy, Arcadia University, Glenside, PA. This study was approved by the Institutional Review Boards of the University of Medicine and Dentistry of New Jersey, Arcadia University, and Temple University. Address correspondence to Dr Stephanie Muth, University of Medicine and Dentistry of New Jersey, 40 East Laurel Road, UEC Suite 2105, Stratford, NJ 08084. E-mail: muthst@umdnj.edu

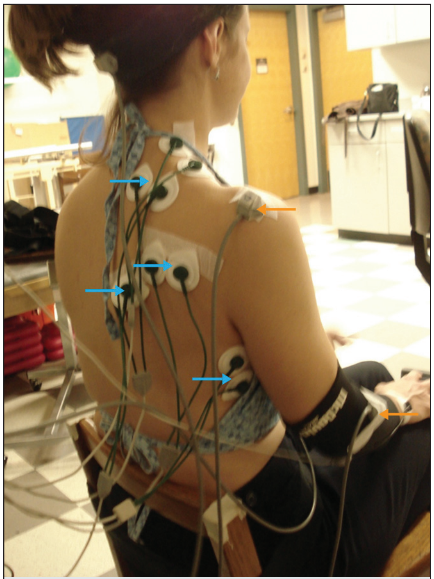

FIGURE 1. Fully instrumented participant. Blue arrows indicate electromyographic electrodes. Orange arrows indicate motion receivers (scapular and humeral receivers only).

sponses may include changes in range of motion (ROM)[38] or more subtle changes in joint mechanics.[22,28,39] Neurophysiologic responses include changes in motor neuron excitability,[11,18] altered electromyographic (EMG) signal amplitude,[14,28,39] and changes in pain perception.[4,23,75] Neurophysiologic responses to cervical and lumbar spine mobilization are frequently described in the literature.[4,14,18,23,35,39,75,77] By comparison, relatively few studies have assessed the neurophysiologic effects of TSM.[7,13] To the authors' knowledge, scapular kinematic changes induced by TSM have not yet been studied. Furthermore, there has been very little research assessing changes in shoulder muscle activity patterns following TSM in patients with shoulder pain.

The relationship between thoracic spine posture, shoulder ROM, and scapular kinematics is well described in the literature.[12,34,40,60,65,71] Scapular kinematics frequently play a role in shoulder dysfunction,[43,45,46,54] and individuals with RCT often demonstrate altered scapular mechanics, as well as differences in shoulder muscle activation, compared to their healthy counterparts.[44,47,52] We hypothesized that the introduction of a manipulative force would result in changes in thoracic spine posture and shoulder motion, as well as changes in scapular kinematics and shoulder muscle activation, that may help to improve the pain and dysfunction associated with RCT.

The primary purpose of this study was to explore possible biomechanical and neurophysiologic mechanisms by which TSM may induce changes in pain and function in people with signs of RCT by assessing changes in scapular kinematics and muscle activity. In addition, various clinical outcomes associated with TSM, including pain, function, and force production, were assessed.

METHODS

Overview

THIS CONTROLLED LABORATORY study employed a repeated-measures design to assess changes in scapular kinematics and shoulder muscle activity, as well as shoulder pain and function, before and after TSM.

Subjects

Thirty subjects, 16 men and 14 women (mean ± SD age, 30.6 ± 7.9 years), with signs of RCT participated in this study. The mean duration of their symptoms was 4.2 months. Subjects were recruited from local universities, rowing clubs, as well as master's swim clubs in the Philadelphia region. Subjects were screened for signs of rotator cuff pathology and included in the study if they reported at least 3/10 on a numeric pain rating scale (NPRS) with performance of the Hawkins-Kennedy, Neer, or Jobe empty-can tests for shoulder impingement. In a recent review, the pooled sensitivity and specificity for the Neer test were 0.79 and 0.53, respectively, and 0.79 and 0.59, respectively, for the Hawkins-Kennedy test.[27] Inclusion criteria were purposely kept broad, as the study sample was primarily of high-level athletes who were not seeking medical treatment for shoulder pain but who engaged in repeated overhead activities, a population highly susceptible to impingement and possible rotator cuff pathology.[8,64] Subjects were excluded from the study if they had previous surgical intervention on their shoulder; demonstrated signs of complete rotator cuff tear, such as gross weakness with performance of the Jobe empty-can test and/or resisted external rotation or diagnostic imaging confirming rotator cuff tear; had a history of spinal trauma or surgery; had signs of neurologic impairment, including numbness or tingling in the upper quarter; or had degenerative bone disease, rheumatic disease, or allergies to adhesives. Individuals at risk for osteopenia or osteoporosis, such as postmenopausal women, were also excluded from participation. All subjects signed an informed consent form approved by the Institutional Review Boards of Temple University, Arcadia University, and the University of Medicine and Dentistry of New Jersey.

Instrumentation

Scapular motion was measured before and immediately after manipulation using the LIBERTY (Polhemus, Colchester, VT), an electromagnetic tracking device. The transmitter was leveled to horizontal using a bubble level and oriented with the cardinal planes of the body. Receivers were placed on the head, scapula, sternum, and humerus. A Velcro strap was placed around the subject's head, and the sensor was attached to the posterior aspect of the occiput with Velcro. The scapular sensor was affixed to the dorsolateral aspect of the acromion with double-sided tape and reinforced with cloth tape to prevent sensor motion during humeral elevation trials. The thoracic sensor was placed on the sternum, just below the jugular notch, with double-sided tape, and the lead wire was secured to the sternum with cloth tape to prevent rotation of the sensor due to skin movement with shoulder elevation. A neoprene sleeve was placed over the subject's arm, and the humeral sensor was attached via an elastic strap to the distal humerus (**FIGURE 1**). The neoprene sleeve prevented sensor movement on the skin with humeral rotation. Anatomic landmarks were used to digitize the upper-quarter segments and to develop anatomic reference frames, using a protocol with previously documented validity and reliability, as consistent with the International Society of Biomechanics shoulder protocol.[32,51,53,79]

Surface EMG data were collected at a sampling rate of 1000 Hz and converted from analog to digital using the MyoSystem 1200 (Noraxon USA Inc, Scottsdale, AZ). Raw data were passed through preselected low-pass (400 Hz) and high-pass (20 Hz) filters and were rectified using the root-mean-square (RMS) technique. Blue Sensor (Ambu Inc, Glen Burnie, MD) 3.81-cm silver/silver chloride wet-gel electrodes, with a 3.81-cm interelectrode distance were used to detect muscle activity. Surface EMG data were collected for the infraspinatus, upper trapezius, middle trapezius, lower trapezius, and serratus anterior. Electrodes were placed as described by Ekstrom et al[19] for the upper trapezius, middle trapezius, lower trapezius, and serratus anterior muscles, and as described by Hintermeister et al[29] for the infraspinatus muscle. With the shoulder passively abducted to 90°, the electrodes for the upper trapezius were placed parallel to the muscle fibers, with 1 electrode superomedial and 1 inferolateral to a point 2 cm lateral to the midpoint between C7 and the lateral aspect of the acromion. Electrodes for the middle trapezius were placed parallel to the muscle fibers, one medial and the other lateral to a point located 3 cm lateral to the T2 spinous process. For placement of the lower trapezius electrodes, the shoulder was passively flexed to 90°. Electrodes were placed obliquely, one superior and the other inferior to a point 5 cm inferolateral from the root of the spine of the scapula. For the serratus anterior, the shoulder was passively abducted to 90°. Electrodes were placed vertically along the midaxillary line between ribs 6 and 8.[19] Electrodes for the infraspinatus muscle were placed in parallel, medial and lateral to a point 2.5 cm below the midpoint of the scapular spine. The ground electrode was placed on the ulnar styloid process (**FIGURE 1**).

Surface EMG data for reference contractions were collected for normalization of the EMG signals. Repeated comparisons of normalized EMG signal amplitude have demonstrated moderate-to-high reliability when electrodes were left in place.[50,61] The reference contraction for the infraspinatus muscle was performed as described by Kelly et al.[36] The subject sat with the humerus aligned with the thorax and the elbow flexed to 90°. The tester asked the subject to isometrically externally rotate the humerus, while providing resistance in the direction of internal rotation. Reference contractions for the upper trapezius and serratus anterior were performed as described by Ekstrom et al.[19] The reference contraction for the upper trapezius was performed with the subject in sitting, the subject's involved shoulder abducted to 90°, and the neck sidebent to the ipsilateral side. Simultaneous resistance to shoulder abduction and cervical sidebending was provided by the tester. The reference contraction for serratus anterior was also collected with the subject seated and the shoulder elevated to 125° in the scapular plane. Resistance was applied distal to the elbow and to the inferior angle of the scapula in an attempt to downwardly rotate the scapula. Reference contractions for the middle and lower trapezius were performed in the prone position, as described by Kelly et al.[36] Resistance was applied to the horizontally abducted and externally rotated shoulder for testing of the middle trapezius. The arm was raised in line with the muscle fibers, and downward resistance was applied to the arm for testing of the lower trapezius. Two maximum-effort trials for each muscle were performed, in which each contraction was held for 5 seconds, with a brief rest between trials. Normalization reference values were calculated by finding the maximum amplitude of the RMS of the EMG data and averaging the RMS of the 500 milliseconds on either side of the peak value.

Pain was assessed before and immediately after manipulation using an NPRS, on which 0 represented no pain and 10 represented the worst pain ever. Pain-rating data were collected during the performance of the Jobe empty-can, Hawkins-Kennedy, and Neer tests for shoulder impingement, as well as with the performance of loaded humeral elevation in the frontal, scapular, and sagittal planes. The NPRS has been shown to be a valid and reliable tool for subjects with shoulder pain[55] and to have an estimated minimal clinically important difference of 2 points.[21]

Peak shoulder elevation force production was assessed with a "break test" before and immediately after manipulation using an ergoFET (Hoggan Health Industries, Inc, West Jordan, UT) handheld dynamometer, with the shoulder in neutral rotation and elevated to 90° in the scapular plane. This method has a previously established intrarater reliability between 0.81 and 0.94,[53,70] and a reported minimal detectable change of 0.95 kg.[70]

Shoulder pain and function were measured premanipulation and 7 to 10 days postmanipulation, using the Penn Shoulder Score (PSS) and the sports/performing arts module of the Disabilities of the Arm, Shoulder and Hand (SPAM-DASH) self-report scales. The PSS is a 100-point scale that assesses pain, function, and satisfaction, and is a valid and reliable outcome measure for people with shoulder disorders.[37] A score of 100 indicates that the participant has identified no functional limitations, with lower scores indicating greater functional limitations. The SPAM-DASH is a 4-question scale that captures limitations specifically related to sports and leisure activities. Scores on this scale range from 0 to 100. A score of 0 indicates no disability, with higher scores corresponding to progressively greater disability. The SPAM-DASH alone has not yet been validated; however, it was chosen because it allows subjects to self-select a sport activity that is currently impacted by their shoulder pain.

Experimental Procedures

A flow chart of the experimental procedures is presented in **FIGURE 2**. Upon completion of digitization and EMG reference contraction procedures, subjects were seated in a wooden chair directly in front of the transmitter. A Velcro strap was placed around their hips and the chair to minimize pelvic rotation during the thoracic spine flexion and extension procedures described below.

To assess muscle force production, subjects were asked to place their affected limb in 90° of humeral elevation in the scapular plane, with the humerus in neutral rotation. Subjects were told to hold this position while the tester performed a break test using the handheld dynamometer. Resistance was applied and increased until the subject could no longer maintain the position against the force applied by the tester.

Cervical rotation ROM was assessed during performance of full available motion in each direction (right and left), with the subject sitting in a comfortable posture, and repeated 3 times. Cervical spine rotation was measured in relation to the thorax. Thoracic spine flexion/extension was also assessed in the seated position. Subjects were instructed to maintain contact between their lumbar spine and the back of the wooden chair. They were then asked to sit in an exaggerated upright posture. When given the command to start, they were instructed to move from the upright posture into the end-range slumped posture, while still maintaining contact between the lumbar spine and the back of the chair. Three repetitions of this motion were performed. The thoracic sensor assessed motion relative to the global coordinate system.

Humeral elevation motion was assessed in relation to the thoracic sensor and is therefore referred to as "humerothoracic" elevation in this study. To assess pain with humeral elevation in the frontal, sagittal, and scapular planes, subjects were instructed to move through their full available elevation ROM during a 3-second count as the tester counted aloud, "One thousand one, one thousand two, one thousand three." This was repeated 3 times in each plane of motion. Humerothoracic ROM, scapular kinematic data, and EMG data were all collected during performance of humeral elevation in the sagittal plane. The subjects performed elevation with a 2.27-kg handheld weight if they weighed less than 68 kg, or with a 4.54-kg handheld weight if they weighed

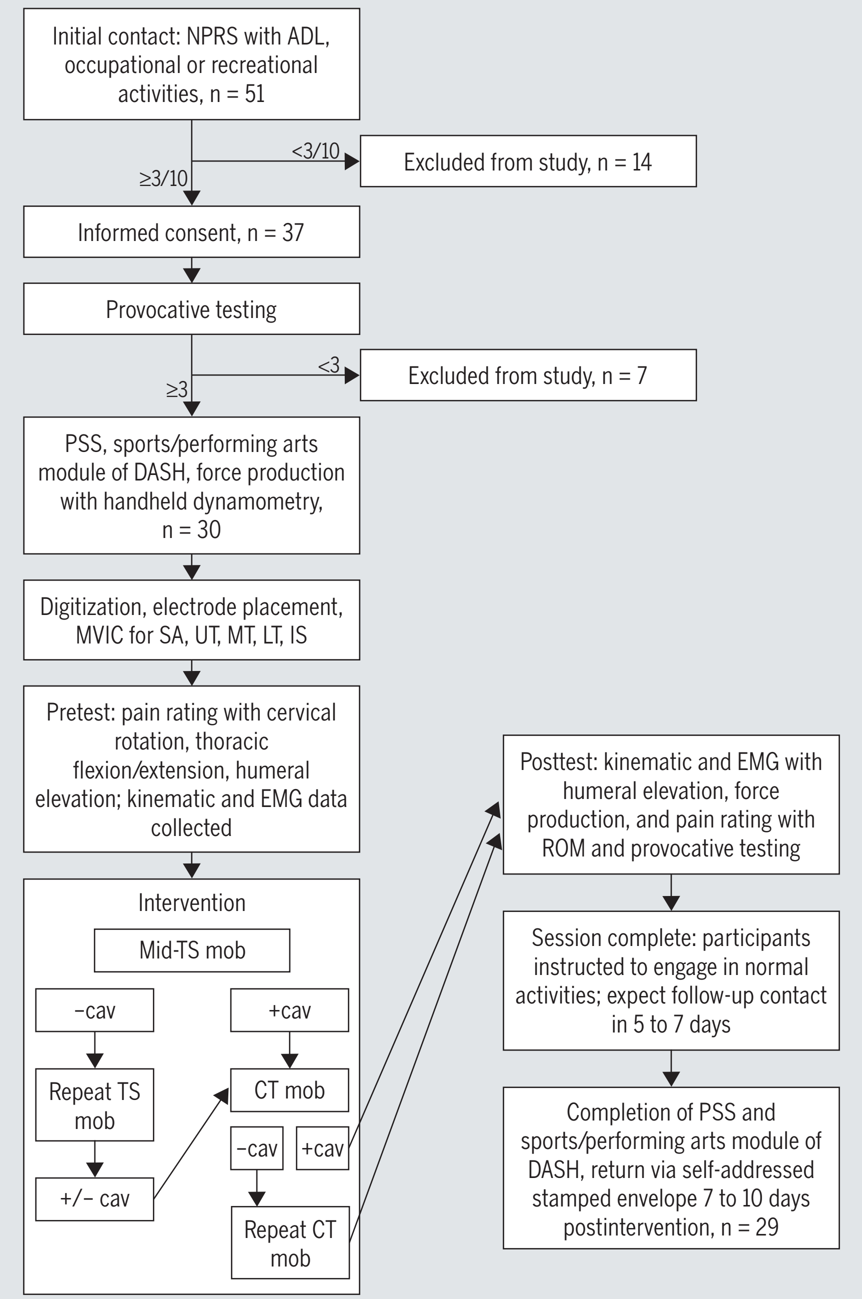

FIGURE 2. Procedural flow chart. Abbreviations: ADL, activities of daily living; cav, cavitation; CT, cervicothoracic; DASH, Disabilities of the Arm, Shoulder and Hand; IS, infraspinatus; LT, lower trapezius; mob, mobilization; MT, middle trapezius; MVIC, maximum voluntary isometric contraction; NPRS, numeric pain rating scale; PSS, Penn Shoulder Score; SA, serratus anterior; TS, thoracic spine; UT, upper trapezius.

FIGURE 3. (A) Midthoracic spine manipulation. (B) Cervicothoracic junction manipulation.

more than 68 kg, as scapular dyskinesis has been shown to be more pronounced under loaded conditions.[44] Subjects were asked to report any pain felt during the elevation trials using the NPRS.

Upon completion of the baseline activities, the subjects received a thrust manipulation of the midthoracic spine and the cervicothoracic junction, similar to those used by Boyles et al.[10] The thrust manipulation to the midthoracic spine targeted the apex of the thoracic kyphosis and was performed with the patient seated with his or her arms wrapped around the chest (**FIGURE 3A**). The tester stood behind the subject, pressing her sternum against the area to be mobilized. The tester then wrapped her arms around the subject to clasp her hands together. The subject was then instructed to take a deep breath. As the subject exhaled, the tester compressed the subject's upper body, while simultaneously lifting the subject slightly, pivoting on the tester's sternal region. The cervicothoracic thrust manipulation was performed with the patient seated with his or her fingers interlocked posteriorly at the base of the cervical spine. The tester stood behind the subject and threaded her arms through the subject's arms so that her hands were on top of those of the subject. The subject was then gently reclined and asked to exhale, at which time the tester provided a distractive thrust directed at the cervicothoracic junction (**FIGURE 3B**). All subjects received the midthoracic manipulation first, followed by the cervicothoracic junction manipulation. If a cavitation (audible pop) was detected with performance of the midthoracic spine manipulation, the tester proceeded to the cervicothoracic junction manipulation. If no cavitation was detected, a second attempt was made before moving on to the next manipulation. No more than 2 attempts were made for each manipulation.

Care was taken during the manipulation procedures to not move any of the markers or electrodes. Upon completion of the manipulation procedures, subjects returned to the wooden chair and were retested on each of the previously described physical procedures. Subjects were also given a self-addressed stamped envelope and a blank copy of the PSS and the SPAM-DASH to take home with them. They were contacted by phone or e-mail 7 to 10 days after the procedure and reminded to complete these questionnaires and return them to the tester.

Data Reduction

Kinematic Data Raw scapular kinematic data were exported to an Excel (Microsoft Corporation, Redmond, WA) file and processed using a custom interpolation program written in LabVIEW (National Instruments Corporation, Austin, TX). This program interpolated the 3 elevation repetitions in 5° increments and provided an average curve. Scapular and clavicular angles at 30°, 60°, 90°, and 120° of humerothoracic elevation were extracted for analysis. Elevation is described as humerothoracic because humeral elevation was measured in relationship to the thoracic sensor. This resulted in slightly lower peak elevation values than would be expected when measuring shoulder ROM with goniometry.[32]

EMG Data The data were exported to an Excel file and processed in the custom interpolation program in LabVIEW to provide RMS values corresponding to minimum, 30°, 60°, 90°, and 120° of humerothoracic elevation. These values were then normalized using the previously calculated reference contraction values and expressed as a percentage of the reference contraction value.

Data Analysis

All data were assessed for skewness and kurtosis. Mean premanipulation and postmanipulation values for ROM, pain during provocation testing and ROM, and force production were compared using 2-tailed paired-samples *t* tests. A 2-factor repeated-measures analysis of variance was performed to examine the effects of condition (pre-TSM and post-TSM) and humerothoracic elevation (30°, 60°, 90°, and 120°) for each of the 5 dependent kinematic variables. These included scapular upward rotation, external rotation, and posterior tilt, as well as clavicular elevation and protraction. Humerothoracic elevation trials demonstrating signs of technical errors were excluded from the analysis. A 2-factor repeated-measures analysis of variance was also performed, with condition and humerothoracic elevation as repeated factors, for each of the 5 dependent EMG variables, which included RMS values for the infraspinatus, serratus anterior, upper trapezius, middle trapezius, and lower trapezius muscles. The differ-

TABLE 1 PRE-TSM AND POST-TSM SCAPULAR AND CLAVICULAR ANGLES*

Kinematic Variable/Humerothoracic Elevation	Pre-TSM	Post-TSM
Scapular external rotation		
30°	–25.5 ± 7.2	–28.1 ± 7.9
60°	–28.2 ± 6.6	–31.3 ± 6.9
90°	–29.2 ± 5.8	–26.2 ± 20.7
120°	–25.5 ± 9.3	–25.9 ± 7.8
Scapular posterior tilt		
30°	–10.6 ± 8.1	–8.4 ± 8.2
60°	–7.2 ± 7.6	–7.3 ± 8.9
90°	–6.9 ± 8.4	–6.4 ± 8.6
120°	–0.8 ± 13.7	0.4 ± 14.2
Scapular upward rotation		
30°	1.1 ± 8.2	–0.01 ± 11.2
60°	12.2 ± 9.7	11.2 ± 12.6
90°	24.7 ± 10.1	22.8 ± 11.7
120°	31.1 ± 9.0	29.4 ± 12.1
Clavicular elevation		
30°	6.9 ± 5.1	4.6 ± 7.5
60°	10.3 ± 5.6	8.0 ± 7.8
90°	13.5 ± 6.2	11.7 ± 8.1
120°	13.5 ± 6.5	13.3 ± 8.9
Clavicular protraction		
30°	–16.1 ± 7.3	–14.6 ± 8.9
60°	–18.6 ± 7.7	–16.8 ± 9.9
90°	–24.1 ± 9.0	–22.1 ± 10.9
120°	–28.9 ± 6.2	–26.4 ± 6.9

Abbreviation: TSM, thoracic spine manipulation.
**Values are mean ± SD deg.*

ences in scores on the PSS and the SPAM-DASH, assessed prior to and 7 to 10 days after receiving the manipulations, were assessed using a 2-tailed paired-samples *t* test for each measure. One subject did not complete the SPAM-DASH; therefore, data for only 29 subjects were used for that outcome measure. An alpha level of .05 was used to determine significance for all variables analyzed.

RESULTS

TABLES 1 AND **2** PROVIDE A SUMMARY of the pre-TSM and post-TSM kinematic and EMG data, respectively. **TABLE 3** provides a summary of pre-TSM and post-TSM data for all clinical variables. Premanipulation and postmanipulation data for scapular kinematics are depicted graphically in **FIGURE 4**. Analysis of variance revealed a small but significant decrease in scapular upward rotation with humerothoracic elevation following TSM (P = .05). A significant interaction between condition and elevation angle was observed for clavicular elevation; however, post hoc *t* tests revealed no significant difference in clavicular elevation at 30°, 60°, 90°, or 120° of humerothoracic elevation from premanipulation to postmanipulation. No differences were observed following manipulation for scapular posterior tilt, scapular external rotation, clavicular protraction, cervical rotation ROM, thoracic spine ROM, or humerothoracic elevation ROM.

Surface EMG data are graphically depicted in **FIGURE 5**. A small but statistically significant increase in middle trapezius activity (P = .03) was detected following spinal manipulation. No differences were detected for the upper or lower trapezius, infraspinatus, or serratus anterior muscles.

A statistically significant improvement in pain was detected following TSM with performance of all provocative tests for rotator cuff pathology (P<.001), as well as with loaded arm elevation in all 3 planes (P<.001). Twenty-four of 30 subjects demonstrated at least a 2-point change with all 3 provocative tests, meeting or exceeding the minimal clinically important difference for the NPRS.[56] Force production with elevation in the scapular plane also significantly improved (P<.001) following TSM. Twenty-three of 30 subjects demonstrated a change greater than 0.95 kg, the estimated minimal detectable change.[70]

Significant improvements were also observed 7 to 10 days following TSM on both the PSS (P<.001) and the SPAM-DASH (P<.001), which improved by 7.6 points and 22.0 points, respectively. Ten of 30 subjects exceeded the minimal detectable change of 12 points for the PSS.

DISCUSSION

Scapular Kinematics

THIS STUDY DEMONSTRATED THAT TSM may induce small changes in scapular upward rotation with weighted humeral elevation; however, no other changes in scapular kinematics were detected. Findings with regard to scapular upward rotation in people with impingement are highly variable. Lin et al[41] and Ludewig and Braman[43] found that subjects with impingement demonstrated less scapular upward rotation than those without impingement. Conversely, McClure et al[52] and Endo et al[20] found that subjects with impingement demonstrated more upward rotation. Furthermore, the effects of scapular rotations on subacromial clearance are not well understood, with only a few studies having looked at that relationship.[31,68] Karduna et al[31] found that increased scapular upward rotation resulted in decreased subacromial clearance, likely increasing compression forces on the subacromial structures. In the current study, scapular upward rotation decreased by only a few degrees after manipulation. It is not likely that this small difference can fully explain the findings of decreased pain with elevation observed in this study, as well as in those of Boyles et al[10] and Strunce et al.[69]

Electromyography

A statistically significant, albeit small, increase in middle trapezius activity was detected; however, no significant changes in EMG signal amplitude were detected in the upper and lower trapezius muscles or in the infraspinatus and serratus anterior muscles. According to Johnson et al,[30] the primary role of the middle trapezius is that of stabilizing and resisting internal rotation of the scapula. Although the small increase in activity found might have served to improve scapular stabilization, it is not likely that this finding may fully explain the improved shoulder motion observed by Strunce et al[69] or the increased force production observed in the current study.

Only a few prior studies have used EMG to detect changes in motor output with dynamic activity following spinal manipulation.[38,39] Lehman and McGill[38] assessed changes in spine kinematics and EMG signal amplitude of the erector spinae muscles in a professional golfer following lumbar spine manipulation. They found decreased EMG signal both in quiet stance and during performance of a golf swing. In a later study, they found that in quiet stance most muscles exhibited no change in activity level after lumbar manipulation, and that muscle activation during performance of dynamic tasks postmanipulation was highly variable, precluding statistical significance.[39] The results of the current study are in agreement with the results of the studies by Lehman and McGill,[38,39] in that few differences in muscle activity were detected after spinal manipulation, in this case, thoracic manipulation.

TABLE 2 Pre-TSM and Post-TSM Root-Mean-Square Electromyographic Data*

Muscle/Humerothoracic Elevation	Pre-TSM	Post-TSM
Upper trapezius		
30°	65.3 ± 28.5	71.3 ± 46.7
60°	84.0 ± 37.1	93.2 ± 60.5
90°	72.2 ± 54.8	96.9 ± 78.9
120°	93.3 ± 49.3	83.5 ± 47.1
Middle trapezius		
30°	15.2 ± 9.5	23.6 ± 17.2
60°	20.9 ± 16.5	25.4 ± 15.3
90°	23.1 ± 7.3	28.7 ± 18.4
120°	21.4 ± 17.0	29.9 ± 28.3
Lower trapezius		
30°	28.3 ± 19.1	25.5 ± 23.8
60°	33.1 ± 15.6	47.2 ± 30.4
90°	48.2 ± 19.4	46.5 ± 33.9
120°	52.2 ± 36.4	45.7 ± 29.1
Infraspinatus		
30°	22.4 ± 27.1	25.1 ± 16.8
60°	28.6 ± 18.3	30.7 ± 27.5
90°	28.4 ± 24.6	33.2 ± 21.9
120°	34.4 ± 25.3	27.7 ± 24.7
Serratus anterior		
30°	33.4 ± 24.2	45.1 ± 36.6
60°	52.2 ± 38.4	73.0 ± 73.3
90°	64.5 ± 56.9	79.8 ± 65.3
120°	71.4 ± 53.7	75.4 ± 49.2

Abbreviation: TSM, thoracic spine manipulation.
**Values are mean ± SD expressed as a percentage of maximum voluntary isometric contraction. With the exception of middle trapezius (P = .03), no significant differences in muscle activity were detected.*

Pain and Function

Subjects demonstrated decreased shoulder pain and increased force production immediately following spinal manipulation. Furthermore, they demonstrated improved shoulder function on the PSS and the SPAM-DASH at follow-up 7 to 10 days after manipulation. These changes in pain, force production, and function were not accompanied by substantial changes in ROM, scapular kinematics, or shoulder muscle activation. The results of this study are in agreement with the findings by Boyles et al[10] and Strunce et al[69] regarding decreased pain with performance of both provocative testing as well as with active humeral elevation immediately following TSM.

Shoulder elevation force production increased immediately after TSM. This increase in force production might have simply been the result of motor learning associated with practice or changes in sensory perception. It was speculated that the increase in force might be explained by a decrease in pain, as research has suggested that pain may alter tempospatial as well as quantitative elements of force production.[16,17,75,80] However, post hoc analysis revealed no significant association between changes in pain and changes in force (r values ranged from 0.04 to 0.09).

Improved functional status 7 to 10 days after manipulation was observed across subjects, as indicated by the PSS and SPAM-DASH. Changes on the PSS (mean ± SD difference, 7.6 ± 9.3) were less than those of the SPAM-DASH (7.6 ± 9.3). This is likely due to a ceiling effect with the PSS, which captures basic function. The subjects in this study were mostly high functioning, with 9 elite athletes, 3 collegiate athletes, and 4 highly competitive recreational athletes. In contrast, the SPAM-DASH assesses disability associated with a subject-selected task. Though participants were generally high functioning on the PSS with regard to self-care and activities of daily living (mean ± SD baseline score, 79.8 ± 11.4 out of 100, higher scores corresponding to better function), they clearly felt that their shoulder pain limited their ability in tasks such as sport participation (mean ± SD baseline score, 37.1 ± 23.1 out of 100, lower scores corresponding to better function). Although the validity and reliability of the SPAM-DASH have not been established, it appeared to be more sensitive to changes in subject self-selected sport or activities they felt were most impacted by their shoulder pain.

TABLE 3 Pre-TSM and Post-TSM Data for All Clinical Outcome Measures

	Pre-TSM*	Post-TSM*	Difference†	*P* Value
Pain, NPRS‡§				
Jobe	2.9 ± 1.2	0.3 ± 0.5	−2.6 ± 1.2 (−3.1, −2.2)	<.001
Neer	3.2 ± 1.2	0.6 ± 0.9	−2.6 ± 1.3 (−3.0, −2.1)	<.001
Hawkins-Kennedy	3.2 ± 1.1	0.4 ± 0.7	−2.8 ± 1.3 (−3.3, −2.3)	<.001
Cervical rotation	0.5 ± 1.2	0.1 ± 0.4	−0.4 ± 0.9 (−0.7, 0.0)	.04
Pain, HT elevation in 3 planes				
Sagittal	2.3 ± 1.7	0.3 ± 0.6	−2.0 ± 0.3 (−2.6, −1.4)	<.001
Scapular	1.2 ± 1.5	0.1 ± 0.4	−1.1 ± 1.4 (−1.7, −0.6)	<.001
Frontal	2.6 ± 1.7	0.3 ± 0.8	−2.3 ± 1.5 (−2.8, −1.8)	<.001
Force production, kg§				
Shoulder elevation	7.4 ± 2.5	9.9 ± 2.9	2.5 ± 1.4 (4.3, 6.7)	<.001
Pain and function‖				
PSS¶	79.8 ± 11.4	87.4 ± 10.9	7.6 ± 9.3 (4.1, 11.1)	<.001
SPAM-DASH#	37.1 ± 23.1	20.3 ± 23.1	−16.8 ± 16.4 (−22.5, −10.2)	<.001
ROM, deg§				
Thoracic flexion/extension	47.4 ± 14.8	45.7 ± 14.6	−1.8 ± 7.6 (−4.5, 0.9)	.20
Cervical rotation	117.9 ± 22.2	119.4 ± 21.5	1.4 ± 10.0 (−2.8, 5.0)	.50
HT elevation (sagittal plane)	128.1 ± 27.6	133.2 ± 22.3	5.1 ± 16.8 (−1.8, 10.2)	.30

Abbreviations: HT, humerothoracic; NPRS, numeric pain rating scale; PSS, Penn Shoulder Score; ROM, range of motion; SPAM-DASH, sports/performing arts module of the Disabilities of the Arm, Shoulder and Hand questionnaire; TSM, thoracic spine manipulation.
*Values are mean ± SD.
†Values are mean ± SD (95% confidence interval).
‡0-to-10 scale where higher score is more pain.
§Assessed immediately after spinal manipulation.
‖Assessed 7 to 10 days after spinal manipulation.
¶100-point scale where a higher score is better.
#100-point scale where a lower score is better.

Range of Motion

With regard to cervical ROM, Nansel et al[58] hypothesized that the application of a TSM might induce movement of thoracic and cervical spine segments and therefore change cervical and thoracic spine ROM. Such changes[58] were not detected in this study. However, only 4 subjects reported pain with cervical rotation and none reported pain with thoracic spine flexion and extension during baseline assessments, suggesting that this cohort of subjects might not have painful restrictions in segmental thoracic or cervical spine motion. The findings of this study related to spinal ROM are similar to those of Lehman and McGill,[38,39] who detected no changes in peak lumbar spine ROM following lumbar spine manipulation during the performance of uniplanar flexion and extension or during axial rotation in subjects with low back pain. They did, however, observe an increase in total ROM during the performance of a complex motor task, suggesting that assessment of simple, uniplanar tasks may not detect subtle changes in joint kinematics. Complex tasks require coupled joint motions and more complex coordination, which may better demonstrate subtle biomechanical changes associated with improved joint motion. Assessment of a more complex functional task following thoracic spinal manipulation was not performed in this study.

There were several limitations to the spinal ROM assessment performed in this study. First, thoracic rotation was not restricted during performance of cervical rotation, and cervical ROM was assessed in relation to the thorax. Therefore, if thoracic rotation ROM increased, subtle increases in cervical ROM might not have been detected. Furthermore, thoracic motion was only assessed in relation to the global coordinate system, thus segmental thoracic motion was not assessed; therefore, subtle changes in segmental thoracic motion might have gone undetected. Finally, our method of measuring thoracic motion, although consistent with assessments of planar spine ROM in the literature, has not been validated.[38,39]

No changes in humerothoracic elevation were observed in this study. In contrast, Strunce et al[69] found that TSM was associated with increased humeral elevation ROM. The conflicting findings of these studies might be due to their use of different measurement techniques, as well as differences in elevation conditions. Strunce et al[69] used goniometry to assess overall shoulder ROM, whereas this study employed an electromagnetic

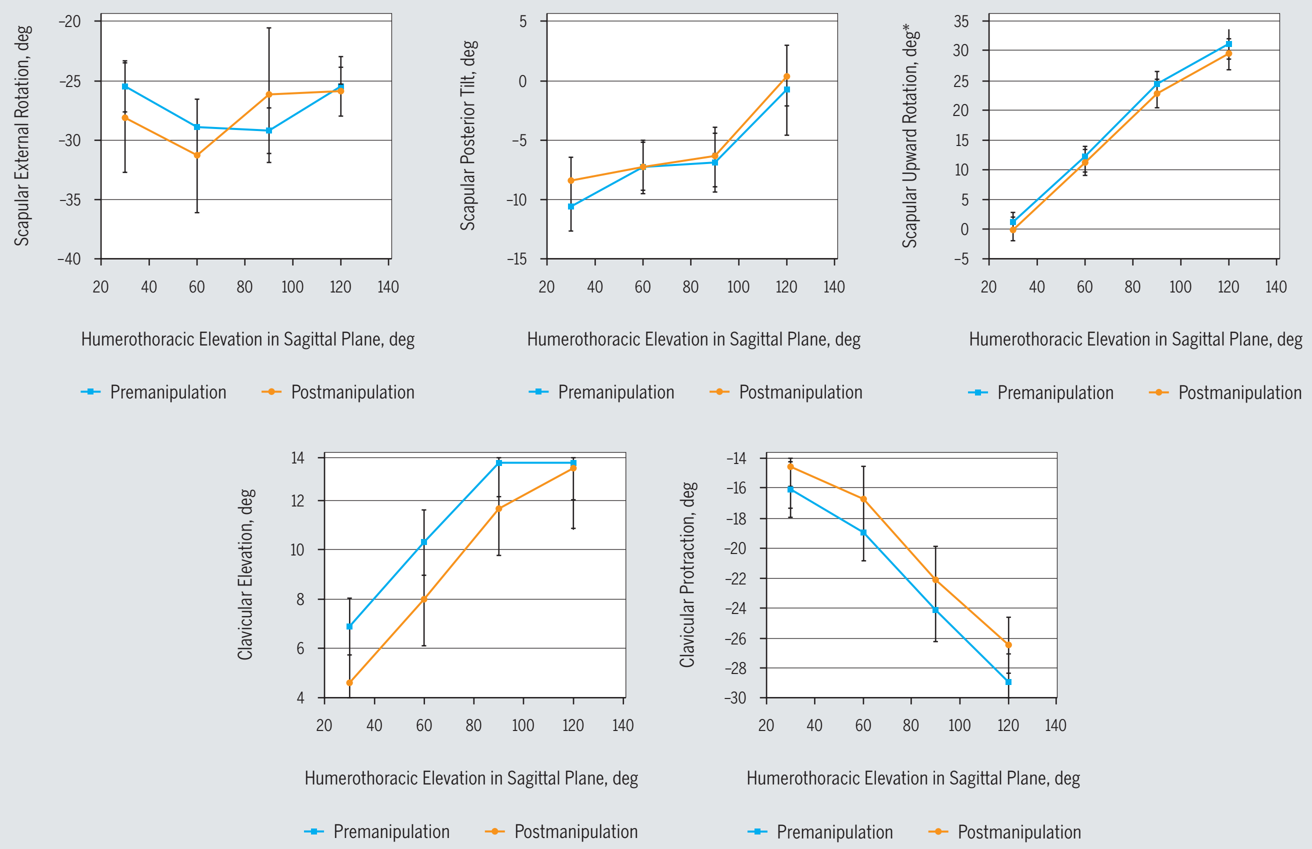

FIGURE 4. Scapular and clavicular angles at 30°, 60°, 90°, and 120° of humerothoracic elevation. *With the exception of scapular upward rotation (*P* = .05), no significant differences in scapular and clavicular kinematics were detected. Data are mean ± SD.

tracking system to assess humerothoracic elevation. In addition, humeral elevation ROM was assessed under weighted conditions in this study, whereas humeral elevation was performed unweighted in the study by Strunce et al.[69] Finally, with regard to subject population, only 2 subjects in this study were actively seeking medical attention for their shoulder pain. Nine subjects were elite athletes who reported that their shoulder pain interfered with participation in their sport but did not wish to seek medical attention. Some of the subjects in the studies by both Boyles et al[10] and Strunce et al[69] were already seeking treatment for their shoulder pain and were referred to the study by their physical therapist.

Other limitations associated with this study include the lack of blinding, randomization, and a control group. Several steps were taken to address blinding. During force production testing, the results screen was covered and the subject was not informed of force production values. Subjects also did not know their pretest PSS or SPAM-DASH scores, so they could not compare scores when completing their posttest questionnaires. In addition, all ROM measurements were obtained using the electromagnetic tracking device, which prevented the tester from inadvertently influencing ROM values. The major limitation with regard to blinding was that the examiner also performed the manipulations. Tools such as electromagnetic tracking and EMG limit the tester's ability to influence outcomes, as the data are not collected directly by the tester but must undergo computer processing and reduction to derive values used for analysis. Likewise, the subject cannot see the data while performing the activities. One additional limitation to this study might have been the severity of the subjects' symptoms. Most subjects were not seeking medical attention for their shoulder pain and might not have exhibited abnormal scapular kinematics or altered motor control. Furthermore, assessment of segmental spine motion might have been beneficial to ascertain whether this particular cohort demonstrated restrictions in segmental spine mobility. Finally, we cannot assume a cause-and-effect relationship due to the lack of a control group. We can, however, address one aspect of the placebo effect: post hoc analysis revealed that pain decreases were not dependent on cavitation. The mean decreases in pain with provocative testing ranged from 2.4 to 3.0, regardless of cavitation.

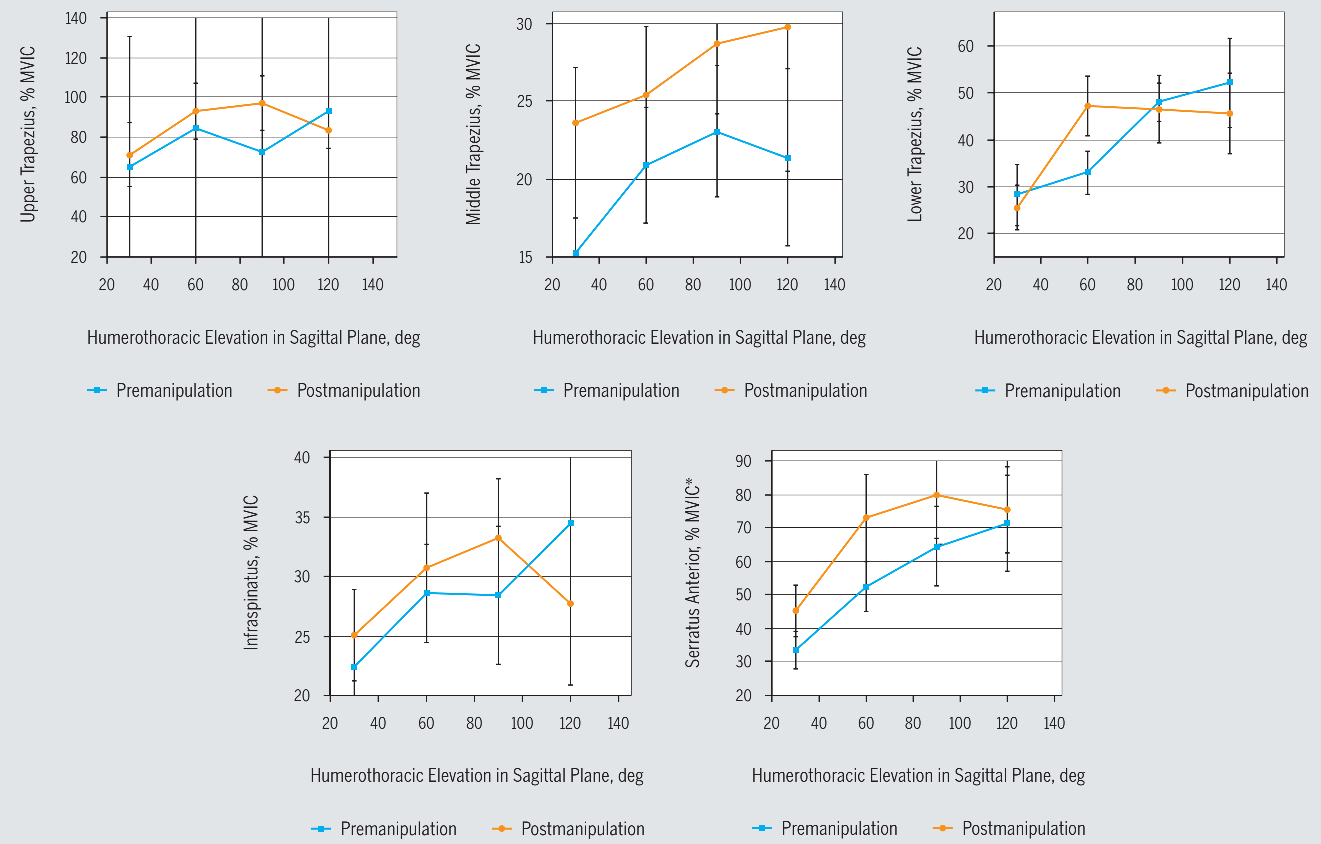

FIGURE 5. Electromyographic data expressed as a percentage of MVIC for each of the 5 muscles at 30°, 60°, 90°, and 120° during humerothoracic elevation in the sagittal plane. *With the exception of middle trapezius (*P* = .03), no significant differences in muscle activity were detected. Data are mean ± SD. Abbreviation: MVIC, maximum voluntary isometric contraction.

CONCLUSION

The findings of this study indicate that TSM may improve pain and function immediately and up to 7 to 10 days postmanipulation in people with signs of RCT; however, the improvements associated with TSM are not likely explained by changes in scapular kinematics or shoulder muscle activity. Other neurophysiologic processes likely contributed to the significant reductions in pain and improvements in function. Further studies assessing changes in pain perception, combined with assessments of altered neuromotor control and segmental spine kinematics, may help to clarify how TSM influences pain and function in people with signs of RCT. ◉

KEY POINTS

FINDINGS: Thoracic spine manipulation was associated with decreased pain and improved shoulder function in people with signs of RCT. These improvements are not likely associated with changes in scapular kinematics or changes in EMG amplitude of the shoulder muscles assessed.

IMPLICATIONS: These findings add to the growing body of literature suggesting that TSM may be a viable tool to help decrease pain for people with signs of RCT, which may allow them to better participate in the rehabilitation process.

CAUTION: The absence of a control group and blinding and the high level of function of the participants must be considered when interpreting the results of this study.

REFERENCES

1. Bang MD, Deyle GD. Comparison of supervised exercise with and without manual physical therapy for patients with shoulder impingement syndrome. *J Orthop Sports Phys Ther*. 2000;30:126-137.
2. Bergman GJ, Winters JC, Groenier KH, et al. Manipulative therapy in addition to usual medical care for patients with shoulder dysfunction and pain: a randomized, controlled trial. *Ann Intern Med*. 2004;141:432-439.
3. Bialosky JE, Bishop MD, Price DD, Robinson ME, George SZ. The mechanisms of manual therapy in the treatment of musculoskeletal pain: a comprehensive model. *Man Ther*. 2009;14:531-538. http://dx.doi.org/10.1016/j.math.2008.09.001
4. Bialosky JE, Bishop MD, Robinson ME, Zeppieri G, Jr., George SZ. Spinal manipulative therapy has an immediate effect on thermal pain sensitivity in people with low back pain: a randomized controlled trial. *Phys Ther*. 2009;89:1292-1303. http://dx.doi.org/10.2522/ptj.20090058

5. Bigliani LU, Levine WN. Subacromial impingement syndrome. *J Bone Joint Surg Am*. 1997;79:1854-1868.
6. Bigliani LU, Ticker JB, Flatow EL, Soslowsky LJ, Mow VC. The relationship of acromial architecture to rotator cuff disease. *Clin Sports Med*. 1991;10:823-838.
7. Bishop MD, Beneciuk JM, George SZ. Immediate reduction in temporal sensory summation after thoracic spinal manipulation. *Spine J*. 2011;11:440-446. http://dx.doi.org/10.1016/j.spinee.2011.03.001
8. Blevins FT. Rotator cuff pathology in athletes. *Sports Med*. 1997;24:205-220.
9. Borstad JD, Ludewig PM. Comparison of three stretches for the pectoralis minor muscle. *J Shoulder Elbow Surg*. 2006;15:324-330. http://dx.doi.org/10.1016/j.jse.2005.08.011
10. Boyles RE, Ritland BM, Miracle BM, et al. The short-term effects of thoracic spine thrust manipulation on patients with shoulder impingement syndrome. *Man Ther*. 2009;14:375-380. http://dx.doi.org/10.1016/j.math.2008.05.005
11. Bulbulian R, Burke J, Dishman JD. Spinal reflex excitability changes after lumbar spine passive flexion mobilization. *J Manipulative Physiol Ther*. 2002;25:526-532.
12. Bullock MP, Foster NE, Wright CC. Shoulder impingement: the effect of sitting posture on shoulder pain and range of motion. *Man Ther*. 2005;10:28-37. http://dx.doi.org/10.1016/j.math.2004.07.002
13. Cleland JA, Glynn P, Whitman JM, Eberhart SL, MacDonald C, Childs JD. Short-term effects of thrust versus nonthrust mobilization/manipulation directed at the thoracic spine in patients with neck pain: a randomized clinical trial. *Phys Ther*. 2007;87:431-440. http://dx.doi.org/10.2522/ptj.20060217
14. Colloca CJ, Keller TS, Gunzburg R. Biomechanical and neurophysiological responses to spinal manipulation in patients with lumbar radiculopathy. *J Manipulative Physiol Ther*. 2004;27:1-15. http://dx.doi.org/10.1016/j.jmpt.2003.11.021
15. Cools AM, Cambier D, Witvrouw EE. Screening the athlete's shoulder for impingement symptoms: a clinical reasoning algorithm for early detection of shoulder pathology. *Br J Sports Med*. 2008;42:628-635. http://dx.doi.org/10.1136/bjsm.2008.048074
16. Descarreaux M, Blouin JS, Teasdale N. Isometric force production parameters during normal and experimental low back pain conditions. *BMC Musculoskelet Disord*. 2005;6:6. http://dx.doi.org/10.1186/1471-2474-6-6
17. Descarreaux M, Lalonde C, Normand MC. Isometric force parameters and trunk muscle recruitment strategies in a population with low back pain. *J Manipulative Physiol Ther*. 2007;30:91-97. http://dx.doi.org/10.1016/j.jmpt.2006.12.01
18. Dishman JD, Cunningham BM, Burke J. Comparison of tibial nerve H-reflex excitability after cervical and lumbar spine manipulation. *J Manipulative Physiol Ther*. 2002;25:318-325.
19. Ekstrom RA, Soderberg GL, Donatelli RA. Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis. *J Electromyogr Kinesiol*. 2005;15:418-428. http://dx.doi.org/10.1016/j.jelekin.2004.09.006
20. Endo K, Ikata T, Katoh S, Takeda Y. Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome. *J Orthop Sci*. 2001;6:3-10.
21. Farrar JT, Young JP, Jr., LaMoreaux L, Werth JL, Poole RM. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. *Pain*. 2001;94:149-158.
22. Gal J, Herzog W, Kawchuk G, Conway PJ, Zhang YT. Movements of vertebrae during manipulative thrusts to unembalmed human cadavers. *J Manipulative Physiol Ther*. 1997;20:30-40.
23. George SZ, Bishop MD, Bialosky JE, Zeppieri G, Jr., Robinson ME. Immediate effects of spinal manipulation on thermal pain sensitivity: an experimental study. *BMC Musculoskelet Disord*. 2006;7:68. http://dx.doi.org/10.1186/1471-2474-7-68
24. Gill TJ, McIrvin E, Kocher MS, Homa K, Mair SD, Hawkins RJ. The relative importance of acromial morphology and age with respect to rotator cuff pathology. *J Shoulder Elbow Surg*. 2002;11:327-330. http://dx.doi.org/10.1067/mse.2002.124425
25. Goupille P, Sibilia J. Local corticosteroid injections in the treatment of rotator cuff tendinitis (except for frozen shoulder and calcific tendinitis). Groupe Rhumatologique Francais de l'Epaule (G.R.E.P.). *Clin Exp Rheumatol*. 1996;14:561-566.
26. Hawkins RJ, Kennedy JC. Impingement syndrome in athletes. *Am J Sports Med*. 1980;8:151-158.
27. Hegedus EJ, Goode A, Campbell S, et al. Physical examination tests of the shoulder: a systematic review with meta-analysis of individual tests. *Br J Sports Med*. 2008;42:80-92. http://dx.doi.org/10.1136/bjsm.2007.038406
28. Herzog W, Scheele D, Conway PJ. Electromyographic responses of back and limb muscles associated with spinal manipulative therapy. *Spine (Phila Pa 1976)*. 1999;24:146-152; discussion 153.
29. Hintermeister RA, Lange GW, Schultheis JM, Bey MJ, Hawkins RJ. Electromyographic activity and applied load during shoulder rehabilitation exercises using elastic resistance. *Am J Sports Med*. 1998;26:210-220.
30. Johnson G, Bogduk N, Nowitzke A, House D. Anatomy and actions of the trapezius muscle. *Clin Biomech*. 1994;9:44-50. http://dx.doi.org/10.1016/0268-0033(94)90057-4
31. Karduna AR, Kerner PJ, Lazarus MD. Contact forces in the subacromial space: effects of scapular orientation. *J Shoulder Elbow Surg*. 2005;14:393-399. http://dx.doi.org/10.1016/j.jse.2004.09.001
32. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. *J Biomech Eng*. 2001;123:184-190.
33. Karthikeyan S, Kwong HT, Upadhyay PK, Parsons N, Drew SJ, Griffin D. A double-blind randomised controlled study comparing subacromial injection of tenoxicam or methylprednisolone in patients with subacromial impingement. *J Bone Joint Surg Br*. 2010;92:77-82. http://dx.doi.org/10.1302/0301-620X.92B1.22137
34. Kebaetse M, McClure P, Pratt NA. Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics. *Arch Phys Med Rehabil*. 1999;80:945-950.
35. Keller TS, Colloca CJ. Mechanical force spinal manipulation increases trunk muscle strength assessed by electromyography: a comparative clinical trial. *J Manipulative Physiol Ther*. 2000;23:585-595. http://dx.doi.org/10.1067/mmt.2000.110947
36. Kelly BT, Kadrmas WR, Kirkendall DT, Speer KP. Optimal normalization tests for shoulder muscle activation: an electromyographic study. *J Orthop Res*. 1996;14:647-653. http://dx.doi.org/10.1002/jor.1100140421
37. Leggin BG, Michener LA, Shaffer MA, Brenneman SK, Iannotti JP, Williams GR, Jr. The Penn Shoulder Score: reliability and validity. *J Orthop Sports Phys Ther*. 2006;36:138-151. http://dx.doi.org/10.2519/jospt.2006.2090
38. Lehman GJ, McGill SM. The influence of a chiropractic manipulation on lumbar kinematics and electromyography during simple and complex tasks: a case study. *J Manipulative Physiol Ther*. 1999;22:576-581.
39. Lehman GJ, McGill SM. Spinal manipulation causes variable spine kinematic and trunk muscle electromyographic responses. *Clin Biomech (Bristol, Avon)*. 2001;16:293-299.
40. Lewis JS, Wright C, Green A. Subacromial impingement syndrome: the effect of changing posture on shoulder range of movement. *J Orthop Sports Phys Ther*. 2005;35:72-87. http://dx.doi.org/10.2519/jospt.2005.1578
41. Lin JJ, Hanten WP, Olson SL, et al. Functional activities characteristics of shoulder complex movements: exploration with a 3-D electromagnetic measurement system. *J Rehabil Res Dev*. 2005;42:199-210.
42. Lin JJ, Lim HK, Yang JL. Effect of shoulder tightness on glenohumeral translation, scapular kinematics, and scapulohumeral rhythm in subjects with stiff shoulders. *J Orthop Res*. 2006;24:1044-1051. http://dx.doi.org/10.1002/jor.20126
43. Ludewig PM, Braman JP. Shoulder impingement: biomechanical considerations in rehabilitation. *Man Ther*. 2011;16:33-39. http://dx.doi.org/10.1016/j.math.2010.08.004
44. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impinge-

ment. *Phys Ther*. 2000;80:276-291.
45. Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF. Motion of the shoulder complex during multiplanar humeral elevation. *J Bone Joint Surg Am*. 2009;91:378-389. http://dx.doi.org/10.2106/JBJS.G.01483
46. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther*. 2009;39:90-104. http://dx.doi.org/10.2519/jospt.2009.2808
47. Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. *J Orthop Sports Phys Ther*. 1999;29:574-586.
48. Lyons PM, Orwin JF. Rotator cuff tendinopathy and subacromial impingement syndrome. *Med Sci Sports Exerc*. 1998;30:S12-S17.
49. MacDonald P, McRae S, Leiter J, Mascarenhas R, Lapner P. Arthroscopic rotator cuff repair with and without acromioplasty in the treatment of full-thickness rotator cuff tears: a multicenter, randomized controlled trial. *J Bone Joint Surg Am*. 2011;93:1953-1960. http://dx.doi.org/10.2106/JBJS.K.00488
50. Mathur S, Eng JJ, MacIntyre DL. Reliability of surface EMG during sustained contractions of the quadriceps. *J Electromyogr Kinesiol*. 2005;15:102-110. http://dx.doi.org/10.1016/j.jelekin.2004.06.003
51. McClure PW, Bialker J, Neff N, Williams G, Karduna A. Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program. *Phys Ther*. 2004;84:832-848.
52. McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. *Phys Ther*. 2006;86:1075-1090.
53. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *J Shoulder Elbow Surg*. 2001;10:269-277. http://dx.doi.org/10.1067/mse.2001.112954
54. Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clin Biomech (Bristol, Avon)*. 2003;18:369-379.
55. Mintken PE, Glynn P, Cleland JA. Psychometric properties of the Shortened Disabilities of the Arm, Shoulder, and Hand Questionnaire (QuickDASH) and Numeric Pain Rating Scale in patients with shoulder pain. *J Shoulder Elbow Surg*. 2009;18:920-926. http://dx.doi.org/10.1016/j.jse.2008.12.015
56. Mohtadi NG, Hollinshead RM, Sasyniuk TM, Fletcher JA, Chan DS, Li FX. A randomized clinical trial comparing open to arthroscopic acromioplasty with mini-open rotator cuff repair for full-thickness rotator cuff tears: disease-specific quality of life outcome at an average 2-year follow-up. *Am J Sports Med*. 2008;36:1043-1051. http://dx.doi.org/10.1177/0363546508314409
57. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med*. 2006;34:385-391. http://dx.doi.org/10.1177/0363546505281804
58. Nansel D, Peneff A, Cremata E, Carlson J. Time course considerations for the effects of unilateral lower cervical adjustments with respect to the amelioration of cervical lateral-flexion passive end-range asymmetry. *J Manipulative Physiol Ther*. 1990;13:297-304.
59. Nordenson U, Garofalo R, Conti M, et al. Minor or occult shoulder instability: an intra-articular pathology presenting with extra-articular subacromial impingement symptoms. *Knee Surg Sports Traumatol Arthrosc*. 2011;19:1570-1575. http://dx.doi.org/10.1007/s00167-011-1552-7
60. Norlander S, Nordgren B. Clinical symptoms related to musculoskeletal neck-shoulder pain and mobility in the cervico-thoracic spine. *Scand J Rehabil Med*. 1998;30:243-251.
61. Ochia RS, Cavanagh PR. Reliability of surface EMG measurements over 12 hours. *J Electromyogr Kinesiol*. 2007;17:365-371. http://dx.doi.org/10.1016/j.jelekin.2006.01.003
62. Odenbring S, Wagner P, Atroshi I. Long-term outcomes of arthroscopic acromioplasty for chronic shoulder impingement syndrome: a prospective cohort study with a minimum of 12 years' follow-up. *Arthroscopy*. 2008;24:1092-1098. http://dx.doi.org/10.1016/j.arthro.2008.04.073
63. Ogawa K, Yoshida A, Inokuchi W, Naniwa T. Acromial spur: relationship to aging and morphologic changes in the rotator cuff. *J Shoulder Elbow Surg*. 2005;14:591-598. http://dx.doi.org/10.1016/j.jse.2005.03.007
64. Pink MM, Tibone JE. The painful shoulder in the swimming athlete. *Orthop Clin North Am*. 2000;31:247-261.
65. Poppen NK, Walker PS. Normal and abnormal motion of the shoulder. *J Bone Joint Surg Am*. 1976;58:195-201.
66. Reddy AS, Mohr KJ, Pink MM, Jobe FW. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. *J Shoulder Elbow Surg*. 2000;9:519-523.
67. Roy JS, Moffet H, McFadyen BJ. Upper limb motor strategies in persons with and without shoulder impingement syndrome across different speeds of movement. *Clin Biomech (Bristol, Avon)*. 2008;23:1227-1236. http://dx.doi.org/10.1016/j.clinbiomech.2008.07.009
68. Silva RT, Hartmann LG, Laurino CF, Bilo JP. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. *Br J Sports Med*. 2010;44:407-410. http://dx.doi.org/10.1136/bjsm.2008.046284
69. Strunce JB, Walker MJ, Boyles RE, Young BA. The immediate effects of thoracic spine and rib manipulation on subjects with primary complaints of shoulder pain. *J Man Manip Ther*. 2009;17:230-236.
70. Tate AR, McClure PW, Kareha S, Irwin D. Effect of the Scapula Reposition Test on shoulder impingement symptoms and elevation strength in overhead athletes. *J Orthop Sports Phys Ther*. 2008;38:4-11. http://dx.doi.org/10.2519/jospt.2008.2616
71. Theodoridis D, Ruston S. The effect of shoulder movements on thoracic spine 3D motion. *Clin Biomech (Bristol, Avon)*. 2002;17:418-421.
72. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med*. 2000;28:668-673.
73. van der Windt DA, Koes BW, de Jong BA, Bouter LM. Shoulder disorders in general practice: incidence, patient characteristics, and management. *Ann Rheum Dis*. 1995;54:959-964.
74. Vecchio P, Kavanagh R, Hazleman BL, King RH. Shoulder pain in a community-based rheumatology clinic. *Br J Rheumatol*. 1995;34:440-442.
75. Vicenzino B, Collins D, Wright A. The initial effects of a cervical spine manipulative physiotherapy treatment on the pain and dysfunction of lateral epicondylalgia. *Pain*. 1996;68:69-74.
76. Wang CH, McClure P, Pratt NE, Nobilini R. Stretching and strengthening exercises: their effect on three-dimensional scapular kinematics. *Arch Phys Med Rehabil*. 1999;80:923-929.
77. Wang SS, Meadows J. Immediate and carryover changes of C5-6 joint mobilization on shoulder external rotator muscle strength. *J Manipulative Physiol Ther*. 2010;33:102-108. http://dx.doi.org/10.1016/j.jmpt.2009.12.006
78. Winters JC, Sobel JS, Groenier KH, Arendzen HJ, Meyboom-de Jong B. Comparison of physiotherapy, manipulation, and corticosteroid injection for treating shoulder complaints in general practice: randomised, single blind study. *BMJ*. 1997;314:1320-1325.
79. Wu G, van der Helm FC, Veeger HE, et al. 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*. 2005;38:981-992. http://dx.doi.org/10.1016/j.jbiomech.2004.05.042
80. Ylinen J, Salo P, Nykänen M, Kautiainen H, Häkkinen A. Decreased isometric neck strength in women with chronic neck pain and the repeatability of neck strength measurements. *Arch Phys Med Rehabil*. 2004;85:1303-1308. http://dx.doi.org/10.1016/j.apmr.2003.09.018
81. Yu CM, Chen CH, Liu HT, Dai MH, Wang IC, Wang KC. Subacromial injections of corticosteroids and xylocaine for painful subacromial impingement syndrome. *Chang Gung Med J*. 2006;29:474-479.