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Effects of Thoracic Spinal Manipulative Therapy on Thoracic Spine and Shoulder
Kinematics, Thoracic Spine Flexion/Extension Excursion, and Pressure Pain Sensitivity
in Patients with Subacromial Pain Syndrome

A dissertation submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy at Virginia Commonwealth University.

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Abstract

EFFECTS OF THORACIC SPINAL MANIPULATIVE THERAPY ON THORACIC SPINE AND SHOULDER KINEMATICS, THORACIC SPINE FLEXION/EXTENSION EXCURSION, AND PRESSURE PAIN SENSITIVITY IN PATIENTS WITH SUBACROMIAL PAIN SYNDROME

By Joseph R. Kardouni, Ph.D., PT

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, at Virginia Commonwealth University.

Virginia Commonwealth University, 2013.

Major Director: Lori A. Michener, PhD, PT, ATC, Professor, Department of Physical Therapy

In patients with shoulder pain, the use of manual therapy directed at the spine and shoulder have been reported to provide superior outcomes to exercise based interventions or usual care without the use of manual therapy. Clinical trials have also reported improved pain and disability after thoracic spinal manipulative therapy (SMT) as a stand-alone treatment for shoulder pain. Although clinical efficacy is reported for the use of thoracic SMT for the treatment of shoulder pain, the mechanisms underlying the clinical benefits are not well understood. This limits the directed use of SMT. The benefits could be due to changes in spine or shoulder motion or neurophysiologic mechanisms of pain modulation. Elucidating the mechanism of manual therapy will aid the directed use of thoracic SMT for treating patients with shoulder pain.

The research described in chapters 3 and 4 was performed to assess the effects of thoracic SMT in patients with subacromial pain syndrome with regard to biomechanical changes at the thoracic spine and shoulder and effects on central and peripheral pain sensitivity. Subjects with shoulder impingement pain symptoms were randomly assigned to receive 1 visit of thoracic SMT or sham SMT, applied to the lower, middle, and upper (cervicothoracic junction) thoracic spine. A 3-dimensional electromagnetic tracking system was used to measure thoracic and scapular kinematics during active arm elevation, and thoracic excursion at end-range of flexion and extension pre- post-treatment. Pressure pain threshold (PPT) was measured at the painful shoulder (deltoid) and unaffected regions (contralateral deltoid and bilateral lower trapezius areas) immediately pre- and post-treatment. PPT measures at the painful shoulder were used to assess peripheral and/or central pain sensitivity, and PPT at unaffected regions measured central pain sensitivity. Patient-rated outcomes measures of pain (Numeric Pain Rating Scale-NPRS), function (Pennsylvania Shoulder Score-Penn), and global rating of change (GROC) were used to assess changes in clinical symptoms following treatment.

No significant differences were found between treatment groups for the thoracic kinematics or excursion, shoulder kinematics, PPT measures, or patient-rated outcomes. No differences were noted pre- to post-treatment in either group for thoracic kinematics or excursion or PPT measures. In both groups, there was a decrease in mean scapular external rotation over time during ascending arm elevation, but the change was less than measurement error. Outcome measures of NPRS, Penn and GROC indicated clinical improvements in both groups following treatment, but there were no differences between the thoracic SMT or sham SMT groups. There were no meaningful correlations between

thoracic and scapular kinematics or thoracic excursion with the outcome measures of NPRS, Penn, or GROC. There was a significant positive correlation ($r=0.52$, $p=0.009$) between change in PPT at the lower trapezius on the unaffected side and baseline Penn scores.

Biomechanically, thoracic spine extension and excursion did not change following thoracic SMT, and the SMT group had no greater changes in shoulder kinematics or patient-rated pain and function than the sham SMT group. Additionally, thoracic SMT did not improve peripheral or central pain sensitivity as measured by PPT. Furthermore, improvements in patient-rated outcomes were not found to be related to changes in thoracic spine mobility, or shoulder kinematics with SMT. The single correlation between change in PPT and baseline Penn may indicate a neurophysiologic effect of SMT in patients with higher baseline function scores, but since no other significant relationships between PPT and outcome were seen, the implications of this finding are limited. Overall, alterations in thoracic spine mobility and pressure pain sensitivity do not appear to be responsible for improved outcomes in patients with subacromial pain syndrome. Future studies should explore the effects of SMT using other measures of thoracic spine motion and experimental pain modalities, as well as greater dosing of SMT over a longer follow-up.

Chapter 1: Introduction and Review of Literature

Shoulder pain is one of the most common musculoskeletal pain complaints in general medical practice, second to spine pain.¹⁶ The prevalence of shoulder pain is estimated at 16% to 48%,^{16, 68} and the direct cost for medical treatment in the United States in the year 2000 was reported at \$7 billion.⁵⁸ Studies report improvements in shoulder pain and functional outcomes,^{6, 14, 61, 79, 91} as well as shoulder motion⁷⁹ after rehabilitation programs that included thoracic spinal manipulative therapy (SMT), a common treatment performed by physical therapists. However, the mechanisms by which thoracic SMT reduces shoulder pain and improves motion have not been established. Understanding mechanisms will improve clinical decision making for using SMT as an intervention for musculoskeletal pain.

Manual therapy has been used as a treatment intervention in healthcare and the healing arts for hundreds of years.^{35, 66} Manual therapy is the use of hands on techniques applied by a healthcare provider to treat soft tissue and joint structures for the purpose of modulating pain, improving joint range of motion, facilitating movement, and improving function.^{35, 50} Mobilization refers to low velocity, passive oscillatory movements applied across a joint in any part of the total range of motion and performed with small or large amplitudes.^{35, 50} Manipulation is a technique performed at the end of available motion of a joint, in the form of a high velocity, low amplitude thrust.⁵⁰ Historically, joint mobilizations and manipulations are applied to resolve a joint motion dysfunction of the musculoskeletal system.³⁵ Manual therapy

examination and treatment models also advocate for examination and treatment of body regions biomechanically linked to the symptomatic region, as well as regions remote to symptomatic region.^{8, 37, 81, 90}

A model of regional interdependence has been presented as a type of examination and treatment approach where body regions proximal or distal to the symptomatic region are examined and treated.⁹⁰ Examination and treatment of the thoracic spine in people with shoulder pain is specifically advocated within the model of regional interdependence.^{81, 90} Application of joint mobilization and manipulation techniques to the thoracic spine in a patient with shoulder pain is based on the thoracic impairments noted on examination by the healthcare provider.^{35, 50} Three single-arm trials using thoracic SMT as a stand-alone treatment for shoulder pain have shown improved patient-rated outcomes following SMT.^{14, 63, 79} A cluster of clinical exam and medical history findings has been identified in patients that responded favorably to thoracic spinal manipulation for shoulder pain.⁶¹ However, it is possible that these findings could also identify individuals with favorable natural history rather than those who are likely to respond favorably to spinal manipulation

In addition to the biomechanical models of the mechanisms of manual therapy in the treatment of musculoskeletal pain, neurophysiological mechanisms of pain modulation are proposed as a benefit to patients receiving manual therapy.^{8, 81} Recent studies have reported that individuals with shoulder pain show signs of both peripheral and central pain sensitization with respect to pressure pain sensitivity.^{1, 22, 67} Spinal manipulative therapy has resulted in decreased sensitivity to mechanical pressure pain in patients with musculoskeletal pain.^{27, 30, 31, 51, 88} Therefore, pain relief after thoracic SMT may be due, at least in part, to neurophysiologic

changes in pain sensitivity locally at the affected area or via changes in pain sensitivity at the central nervous system level.

The mechanisms by which thoracic SMT positively affect musculoskeletal pain are likely multifactorial in nature.^{8, 81} Understanding the potential biomechanical and neurophysiologic mechanisms that may underlie these benefits is clinically important. Changes in thoracic spine kinematics with accompanying changes in shoulder kinematics following treatment with thoracic SMT would indicate the importance of clinical examination and treatment of the thoracic spine when treating patients with shoulder pain. Changes in neurophysiologically mediated pain sensitivity following treatment with thoracic SMT would provide evidence to indicate that SMT may decrease pain independently or in conjunction with biomechanical benefits. It would also potentially lead to changes in the clinical paradigm of applying manual therapy based on biomechanical examination to incorporate more of a symptom-based approach to direct the use of manual therapy.

Impairment-based examination and treatment strategies for individuals with musculoskeletal pain may be improved by understanding biomechanical differences between healthy people and those who are experiencing pain. For individuals with shoulder pain, this will require an understanding of kinematic differences at the shoulder and thoracic region between healthy people and those with shoulder pain. Further understanding of possible affects on pain sensitivity at the shoulder and thoracic spine following SMT is also warranted to understand the neurophysiological effects of SMT. Identifying alterations in shoulder or thoracic kinematics or pain sensitivity following thoracic SMT will advance our understanding of how SMT works in patients with shoulder pain and the biomechanical impairments or neurophysiological alterations that may be most directly affected by SMT. Manual therapy

treatment techniques can then be employed to address relevant biomechanical dysfunction or neurophysiological symptoms.

The purpose of this chapter is to describe the rationale and clinical benefits of using manipulation and mobilization techniques, particularly thoracic SMT, in the treatment of shoulder pain. Comparisons of scapular and thoracic kinematics in people with and without subacromial impingement syndrome will be provided as background for a biomechanical treatment model in the use of thoracic spinal manipulation to treat shoulder pain. This chapter will also describe changes in the neurophysiologic measure of pressure pain threshold (PPT) following spinal manipulative therapy that may also serve as a mechanism for symptom improvement.

Kinematics of the Shoulder

Three-dimensional scapular motion (figure 1) is defined by 3 rotations (upward/downward rotation, internal/external rotation, anterior/posterior tilting) and positioning based on clavicular motion (elevation/depression and protraction/retraction). The general pattern of scapular movement shown by the scapula during glenohumeral elevation is upward rotation, external rotation, and posterior tilting,^{47, 49, 60} accompanied by elevation and retraction of the scapula (as determined by clavicular motion).^{48, 57} Differences in the magnitudes of these rotations and displacements of the scapula have been noted in studies comparing scapular kinematics in subjects with and without shoulder pain. Subjects with subacromial impingement tend to display less upward rotation,^{13, 29, 45, 46, 73, 80, 87} less external rotation,^{13, 29, 71, 73, 87} and greater scapular elevation^{45, 49, 56, 87} and retraction^{56, 87} compared to healthy controls. These differences in shoulder kinematics are thought to reduce the subacromial space and compress the rotator cuff tendons,^{60, 73, 86} as it is thought that these deviations keep the anterior aspect of the

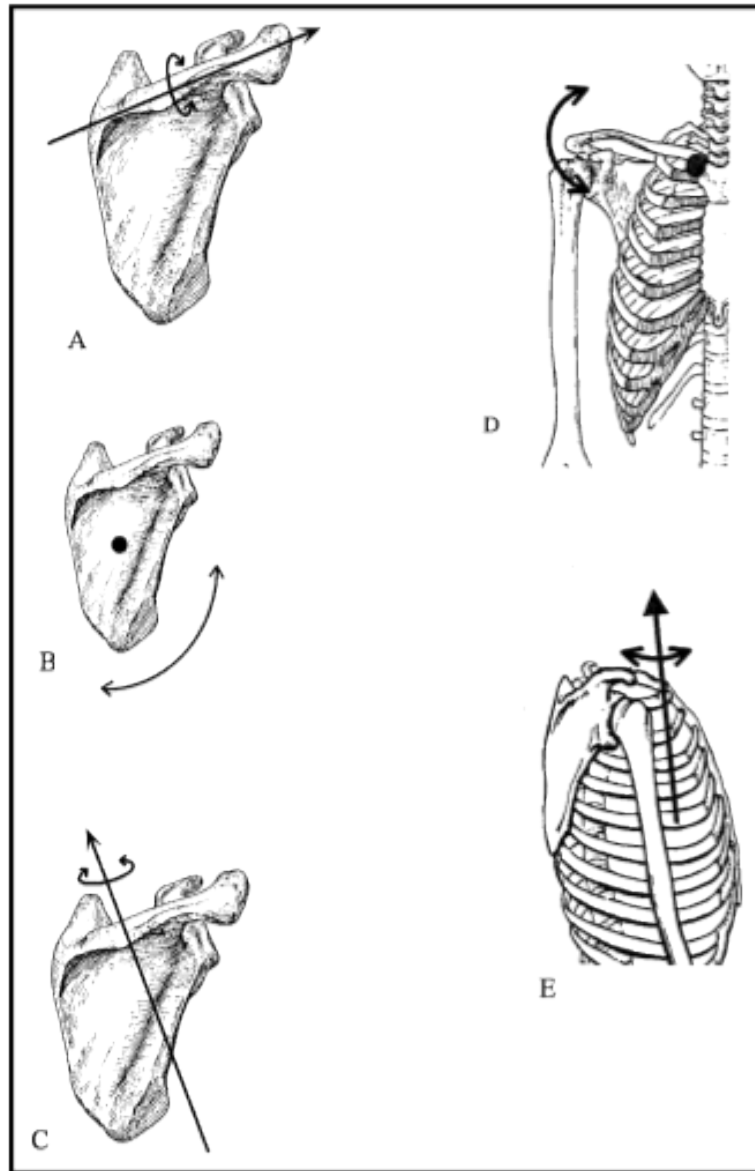


Figure 1. The rotations and translations describing scapular motion (image taken from McClure et al. 2004).⁵⁵

- A. scapular anterior/posterior tilting
- B. scapular upward/downward rotation
- C. scapular internal/external rotation
- D. scapular (clavicular) elevation/depression
- E. scapular (clavicular) protraction/retraction

acromion in closer proximity to the humeral head during elevation of the humerus.⁴⁶ These differences in scapular motions between people with shoulder pain and people without shoulder pain could lead to the development of shoulder pathology. There has been variability in the findings across studies comparing scapular kinematics in individuals with and without shoulder pain.^{54, 73, 87} Counter to the trends previously described, there have also been studies that noted increased scapular posterior tilting^{43, 56} and increased upward rotation in subjects with shoulder pain.^{56, 71} The increased posterior tilt and upward rotation may be favorable compensatory mechanisms to avoid compression of the rotator cuff tendons in those experiencing pain.⁵⁶ The differences in scapular kinematics between healthy individuals and those with subacromial impingement reported in previous studies using skin mounted sensors and 3-dimensional (3-D) electromagnetic tracking methods are depicted in Table 1. The validity and accuracy of 3-D electromagnetic tracking comparing skin mounted sensors to sensors mounted directly to the scapula with bone pins has been established.⁴⁰ Root mean square errors for scapular rotations and positions are typically less than 5°, with an inter-rater reliability reported to range from 0.69-0.95.⁵⁵

This variability in the findings regarding scapular kinematics in those with subacromial impingement and healthy shoulders in conjunction to the small magnitude of the differences (typically 3-5°)⁵⁴ noted across studies have led some to question the clinical significance of deviations in scapular kinematics.^{54, 73} However, a recent meta-analysis of scapular kinematic studies performed by Timmons et al.⁸⁷ examined the data from nine studies has attributed the differences in scapular kinematics between studies in large part to differences in the study populations. Specifically, they concluded that studies using subjects from the general population with shoulder pain showed greater scapular elevation and retraction associated with pain, while

Table 1. Representative studies of scapular rotation and position differences between patients with subacromial pain and people without shoulder pain. The difference noted is that of those with shoulder pain relative to those without shoulder pain.

Plane of motion	Posterior Tilt	Upward Rotation	External Rotation	Scapular Elevation	Scapular Retraction
Scapular	↓ 4-6° ^{1,3} ↑ 3.3-5° ^{2,5}	↓ 4-4.1° ^{1,3} ↑ 3.8° ⁵	↓ 1.8-5.2° ^{1,3}		↑ 3.1° ⁵
Sagittal	↓ 9.5° ⁴	↑ 4.9° ⁵		↑ 2.3 cm ⁴ ↑ 2.9° ⁵	

↓ = patients with shoulder pain showed decreased motion compared to healthy individuals

↑ = patients with shoulder pain showed increased motion compared to healthy individuals

1 = Borstad and Ludwig 2002¹³

2 = Laudner et al. 2006⁴³

3 = Ludewig and Cook 2000⁴⁶

4 = Lukasiewicz et al. 1999⁴⁹ (electromagnetic digitization at static positions)

5 = McClure et al. 2006⁵⁶

athletes with shoulder pain showed greater posterior tilt and less upward rotation of the scapula, and overhead workers with shoulder pain showed less posterior tilt, less upward rotation, and less external rotation than healthy control subjects.⁸⁷ This is an interesting finding, but one might also assume that overhead workers and athletes may also be included in studies of the general population. Therefore, this may only be a part of the explanation of the mixed results between studies. Different planes of humeral elevation (scapular, sagittal, frontal) during testing of study participants also leads to variability in results between studies.

It is possible that particular scapular kinematic patterns may serve as risk factors for development of shoulder pain in some populations, while in other populations, the development of shoulder pain may result in common compensatory movement patterns. The existing literature provides characterization of scapular movement patterns in patients with subacromial impingement versus people with healthy shoulders, but study designs are not such to allow for establishing cause and effect relationships.⁴⁸ A small single-arm study by Roy et al. did assess the effects of a shoulder rehabilitation program designed to promote posterior tilting and external rotation of the scapula on shoulder pain and disability, as well as its effects on three-dimensional scapular attitude.⁷⁰ The results of that study showed an improvement in patient outcomes from this type of rehabilitation program, with trends of increased posterior tilting, upward rotation, and external rotation noted during retesting of scapular attitudes following participation in the exercise regimen.⁷⁰ However, a larger study by McClure et al. reported clinical improvement in patients with subacromial impingement following 6 weeks of rehabilitation but no changes in scapular kinematics.⁵⁵

A recent study assessed scapular motion following thoracic spinal manipulation in patients with shoulder pain and found that subjects reported improved patient-rated outcomes

following treatment, but there was only a small increase in upward rotation that was likely not clinically meaningful.⁶³ This was a single-arm trial with no control or alternative treatment group. The lack of a control or comparator group does not allow us to draw a cause and effect relationship between the improvements in pain and function and the thoracic SMT treatment. The lack of the comparator group also makes it difficult to interpret whether the lack of significant immediate changes in shoulder and thoracic spine kinematics are similar or different to what would be seen within a control group or a treatment groups that received a different treatment modality. Therefore, there is still the need to assess the affects of thoracic SMT to a comparator intervention or control in people with subacromial impingement in order to directly determine the benefits of SMT and the underlying mechanisms for improvement.

Thoracic Kinematics

Posture of the thoracic spine has been related to scapular position at rest and scapular kinematics during arm elevation.^{26, 41} A more flexed thoracic spine has been associated with decreased subacromial space³⁶ and a more elevated, anterior tilted, and less upwardly rotated scapular position at rest.^{26, 41} During arm elevation, a more flexed or kyphotic position of the thoracic spine has similarly been associated with less posterior tilting ,less upward rotation,^{26, 41} and more elevation of the scapula.⁴¹ These posture related scapular positions and movement patterns are directionally similar to the scapular kinematic trends noted earlier in people with shoulder pain.

There are synchronous interactions between shoulder and thoracic motion during elevation of the arm.^{24, 25, 76, 85} Thoracic extension is seen during both bilateral arm elevation^{24, 25} and unilateral arm elevation,^{25, 85} with greater thoracic spine extension during bilateral versus unilateral arm elevation.²⁵ A study that compared thoracic motion patterns during both bilateral

and unilateral arm elevation in a female population found greater thoracic extension when both arms are elevated simultaneously.²⁵ During unilateral arm elevation, there is a coupling of thoracic side flexion and axial rotation toward the side of arm elevation^{25, 85} but not during bilateral arm elevation.⁸⁵ The coupling patterns have been reported during unilateral arm elevation in the coronal, sagittal, and scapular planes.^{25, 85} Differences in thoracic extension during unilateral compared to bilateral arm elevation may be related to less biomechanical need for extension during unilateral arm elevation due to the freedom of motion into side flexion and rotation. The need for different trunk motions during unilateral versus bilateral arm elevation may also be due in part to offset the differences in the change of center of mass of the upper body when raising one arm compared to raising both arms.

Limited evidence indicates differences in thoracic spinal posture or mobility between people with shoulder pain and those without shoulder pain. While increased kyphosis has been shown to correlate with decreased arm elevation range of motion,²⁴ studies measuring resting thoracic kyphosis in individuals with and without shoulder pain have failed to show a significant difference in kyphotic curvature between the two groups.^{44, 84} Although Theisen et al. found no difference in resting kyphosis, they did find that individuals with shoulder pain showed a 20% decrease in thoracic excursion (total spinal flexion/extension range of motion) compared to asymptomatic controls.⁸⁴ Roy et al compared spinal motion in patients with subacromial impingement to asymptomatic controls during a shoulder-level reaching task and found similar extension excursion between the groups.⁷² Crawford et al. studied women with increased kyphosis and had similar findings to Theisen et al. with regard to overall thoracic flexion/extension motion and Roy et al. in extension excursion during arm elevation, as they reported decreased overall thoracic extension range of motion but similar amounts extension

during arm elevation compared to women with less of kyphotic curvature.²⁴ Therefore, there may be a functional amount of thoracic extension during arm elevation that is achievable despite an individual having decreased overall range of motion of the thoracic spine. In people with decreased overall thoracic motion, a higher proportion of available motion is required for arm elevation. Using a greater proportion of available motion at the thoracic spine may affect the movement patterns at the shoulder girdle due to altered soft tissue (muscular and connective tissue) tension of the biomechanical links between the thoracic region and the shoulder girdle.

Mobility of the thoracic spine has been measured before and after spinal manipulation. A study by Campbell et al examined segmental posterior/anterior stiffness of the thoracic vertebrae following thoracic SMT, but did not find a significant difference in stiffness following manipulation.¹⁷ Another study examined maximum thoracic flexion/extension displacement both before and following treatment with thoracic SMT and found no significant changes in flexion/extension following treatment.⁶³ However, this measurement was taken by measuring the displacement of a single thoracic electromagnetic sensor at the sternum in relation to the global coordinate system. Instead of measuring posterior/anterior stiffness of individual levels or trunk displacement in relation to a global reference, a more direct measurement of the angle of thoracic spinal flexion and extension excursion following spinal manipulation may provide more information as to how the treatment affects the segmental biomechanics of the thoracic spine.

In addition to the differences noted in overall thoracic spinal motion between individuals with subacromial impingement and controls, there may also be differences in segmental mobility at the cervicothoracic spine in individuals with and without shoulder pain. When looking at segmental mobility of the thoracic spine, differences have been noted at the cervicothoracic junction (C7-T1) and upper thoracic spine between individuals with shoulder pain symptoms and

healthy individuals.^{64, 65, 77} A decrease in the mobility of T1-T2, as measured by excursion of the spinous processes during thoracic range of motion, was found to be a determinant for increased shoulder pain reported on a shoulder index questionnaire in electricians and laundry workers,⁶⁴ while decreased motion at the cervicothoracic junction using the same measuring technique was found to be predictive of developing musculoskeletal shoulder pain (followed over a 2-year period).⁶⁵

A biomechanical relationship exists between the shoulder and the thoracic spine, that when disrupted, might be a contributing factor in shoulder pain. There are synchronous interactions between thoracic spinal motion and arm elevation centered at the shoulder, and shoulder kinematics can be affected by thoracic posture or position. Additionally, differences have been noted in overall thoracic motion and segmental mobility of the cervicothoracic region between individuals who have or may develop shoulder pain compared to people without shoulder pain. There is, therefore, a need to assess kinematics before and after thoracic manipulation in people with shoulder pain in order to examine whether there are changes in thoracic kinematics that may accompany any changes in shoulder symptoms.

Pain Modulation

Individuals with shoulder pain have shown signs of both peripheral and central pain sensitization.^{21, 22, 67} Peripheral pain sensitization is the increased sensitivity to noxious stimuli due to changes within peripheral afferent structures,¹⁸ while central sensitization is an increase in sensitivity to noxious stimuli due to changes within the central nervous system.³⁹ The presence of peripheral sensitization has been qualified as hypersensitivity to pain at the affected shoulder compared to unaffected areas remote to the painful shoulder, while central pain sensitization has been qualified as greater sensitivity to pain bilaterally compared to healthy controls.^{21, 22, 67} PPT

is measured by applying a mechanical pressure stimulus to an individual using a pressure algometer. Pressure algometry to assess pain threshold is a method to assess changes in nociceptive processing, and it is commonly used to assess pain sensitivity in clinical trials.⁷⁸ Coronado et al. found greater pain sensitivity at the affected versus the unaffected shoulder in patients with shoulder pain, as well as distally (masseter and brachioradialis), and reported that peripheral and/or central pain processes may be altered in patients with shoulder pain.²¹ They could not draw definitive conclusions regarding central sensitization, as they did not use a healthy control group for comparison.²¹ Paul et al. reported findings consistent with central pain sensitization in patients with subacromial pain syndrome compared to healthy control subjects as evidenced by increased sensitivity to pressure pain at the affected and unaffected shoulders as well as the contralateral tibialis anterior.⁶⁷ Evidence for both central and peripheral sensitization to pressure pain was presented in follow-on work by Coronado et al., as they found that patients with unilateral subacromial pain syndrome had demonstrated greater sensitivity to pain at the masseter and the acromion on the affected versus the unaffected side, and these patients showed increased sensitivity to pressure pain at the acromion on both sides compared to age and sex-matched controls.²²

Patients with musculoskeletal pain who were treated with spinal manipulative therapy have shown decreased sensitivity to mechanical pressure pain.^{23, 27, 31, 32, 51, 88} Studies have examined the pain reducing effects of spinal manipulation with respect to A δ fiber and C fiber mediated pain perception via thermal pain sensitivity^{9, 11, 34} and the descending pain inhibitory system with respect to pressure pain.⁸⁹ The A δ fibers are nerve fibers that carry nociceptive signals associated with mechanical or thermal pain and transmit acute, sharp pain. C fibers differ from A δ fibers in regard to pain transmission in that they carry nociceptive signals associated

with mechanical, thermal, or metabolic pain and transmit slow, burning, long lasting pain. The descending pain inhibitory system refers to mechanisms with origins in supraspinal centers that serve to modulate pain perception. Alterations in A δ fiber or C fiber mediated pain perception could represent peripheral changes affecting afferent sensitivity or central changes in processing of the signals at the central nervous system. Alterations in the descending pain inhibitory system is an example of a central change.

Evidence on the effect of lumbar spinal manipulation on A δ fiber mediated pain provided mixed results. George et al. report a possible “counter-irritant” effect on A δ fiber pain following spinal manipulation in people without low back pain via inhibition of peripheral noxious stimulus at the dorsal horn.³⁴ This counter-irritant effect occurs when non-nociceptive afferent input triggered by SMT arrives at the level of the spinal cord where the nociceptive afferent neurons terminate and inhibits transmission of the noxious stimulus at the dorsal horn.^{12, 39, 59} Conversely, Bialosky et al. report a lack of inhibition of A δ fiber mediated pain following spinal manipulation in subjects with low back pain.⁹ The evidence to support an effect on C fiber mediated pain perception following spinal manipulation has been more consistent.^{9, 11, 34} These fibers are thought to mediate the pain associated with temporal summation, in which the perception of pain becomes exaggerated in response to repetitive exposure to a nociceptive stimulus.³⁹ In studies examining pain using thermal pain sensitivity, decreases in temporal summation at lumbar innervated regions has been observed immediately following lumbar spinal manipulation in both asymptomatic subjects and patients with low back pain.^{9, 34} The hypoalgesic effect of lumbar manipulation may be a neurophysiological response that is limited to lumbar innervated regions (calf³⁴ and plantar foot^{9, 34}), as it did not affect cervical innervated cutaneous regions when assessed in asymptomatic subjects.³⁴

Decreased pain sensitivity (peripheral and/or central) has been reported following cervical spinal manipulation for a variety of musculoskeletal conditions. Local and distal pressure pain thresholds have been examined following cervical spinal manipulation techniques. A hypoalgesic effect on local (nearby spinal level) pressure pain has been reported over the C5-C6 zygapophyseal joints following spinal manipulation directed at the cervicothoracic junction.³² This could represent either a decrease in either peripheral or central pain sensitivity since the neck pain was not unilateral and the pain reduction occurred local to the area that was treated. Cervical spinal mobilization and manipulation has shown an immediate decrease in sensitivity to pressure pain at the elbow in patients with lateral epicondylalgia and at the neck in patients with neck pain. A pilot study in patients with neck pain showed decreased pressure pain sensitivity over the cervical paraspinals immediately following cervical manipulation, which could represent changes in peripheral or central pain sensitivity.⁸⁸ In patients with lateral epicondylalgia, two studies have reported a decrease in pressure pain sensitivity at both the affected and the unaffected lateral epicondyle immediately following cervical manipulation,^{30, 31} compared to a manual contact control group³¹ and thoracic spinal manipulation, which could represent a decrease in central pain sensitivity.³⁰ In earlier work, Vicenzino et al. found functional improvements and decreased pain in persons with lateral epicondylalgia immediately following cervical spine lateral glide mobilizations as compared to placebo manual therapy and controls.⁸⁹ They hypothesized that the pain modulation was due to effects on the descending pain inhibitory system, similar to animal studies following stimulation of the periaqueductal grey.⁸⁹ Stimulation of the periaqueductal grey matter stimulates descending pathways from the brain stem that inhibit nociceptive neurons in the spinal cord.³⁹ Neurons from the periaqueductal grey connect with neurons in the rostroventral medulla, which have inhibitory connections with

the dorsal horn of the spinal cord and inhibit neurons in the dorsal horn that respond to noxious stimulation.³⁹ Although Vicenzino et al.⁸⁹ speculated that the changes they found were due to altered central pain sensitivity, it is also possible that the changes noted were a function of decreased peripheral sensitivity at the painful elbow following cervical manipulation.

Contrary to the local neurophysiological effects described with lumbar and cervical manipulation, evidence suggests that thoracic spinal manipulation may affect pain sensitivity at both the upper and lower extremities. Asymptomatic individuals who received thoracic manipulation had immediate reductions in thermal pain sensitivity at the forearm and calf compared to individuals who performed cervical retraction exercises and a control group.¹¹ However, there were no differences between groups that received thoracic spinal manipulation, cervical retraction exercises, or a control group in PPT measurements at the hand and the foot. A study comparing thoracic and cervical SMT techniques in the treatment of neck pain did find increased PPT at the neck, elbow, and leg immediately following treatment at each spinal region, but there were no difference in PPT change between the two treatment groups.⁵² This study lacked a control group and may have been subjected to assessor bias, as the assessor measuring PPT knew that all participants received an active treatment.⁵² Although single-arm clinical trials are reporting improvements in shoulder pain following thoracic spinal manipulation,^{14, 63, 79} no trials have assessed peripheral and central pain sensitivity at the shoulder and remote locations following thoracic manipulation in this clinical population.

The changes in pain perception following spinal manipulation noted in the studies described within this section have primarily shown reduced pain sensitivity along the spine and in the extremities with innervation from the spinal level that was treated. This could be the result of changes in central or peripheral pain sensitivity. One study also showed changes in pain

sensitivity at the leg in addition to the neck and elbow following cervical and thoracic manipulation in patients with neck pain.⁵² This widespread decrease in pain would likely be more indicative of a decrease in central pain sensitivity, but the changes in pain sensitivity noted at the neck (painful region) do not allow us to exclude the possibility of peripheral changes in pain sensitivity. A single study noted no significant changes in PPT at the hand and the foot compared to cervical exercise and a control group following thoracic manipulation in an asymptomatic sample.¹¹ However, the findings of the later study may not be representative of the effects of thoracic spinal manipulation in a population with musculoskeletal pain. Therefore, given the clinical reports of improvements in shoulder pain following thoracic manipulation, it warrants investigation to examine changes in pain sensitivity at the shoulder and regions remote from the shoulder following thoracic manipulation in a sample of patients with shoulder pain.

Mobilization and Manipulation for Shoulder Pain

Mobilization and manipulation techniques may be applied to the glenohumeral joint or other shoulder girdle joints to address painful or restricted motion.^{35, 50} Mobilization or manipulation could also be applied to the spine or ribs if dysfunction at the respective region is noted and thought to contribute to a patient's shoulder pain.^{35, 50} Evidence suggests that mobilization or manipulation of one joint may affect other joints via their anatomical linkages. A posterior to anterior force applied to one spinous process caused motion at multiple spinal segments both caudally and cranially to the level where the force was applied⁴² and manipulative thrust applied to the spine often resulted in cavitation (the audible pop heard and felt in response to manipulation) at multiple spinal levels.⁶⁹ The manual technique applied to a specific spinal joint still affected the targeted joint,^{42, 69} but other spinal levels appeared to be affected as well.

The use of joint mobilization and manipulation in the treatment of shoulder pain is often thought to facilitate positive clinical outcomes. Many clinical trials have reported positive benefits from these manual techniques,^{2, 3, 5, 6, 14, 20, 61, 62, 79, 82, 91} while a other studies have reported no benefit or limited benefits from the use of manual therapy to treat shoulder pain.^{5, 92} A recent review of literature by Brantingham et al. concluded that, overall, there is fair evidence to support a positive effect from manual therapy combined with exercise or a multimodal treatment approach including manual therapy in the treatment of shoulder pain.¹⁵

In clinical practice, healthcare providers have historically selected and applied joint mobilization and manipulation techniques based on individual patient examination findings. Therefore, a patient with shoulder pain may receive mobilization and/or manipulation techniques applied to the shoulder and/or the spine, at the discretion of their healthcare provider. Studies have assessed the effects of application of mobilization and manipulation techniques directed at the shoulder and/or spine in treating shoulder pain and have shown mixed results as to whether the addition of these techniques provided any benefit over rehabilitation exercises alone.^{3, 5, 6, 10, 20, 74, 75, 91, 92} Several studies that incorporated thoracic spinal manipulations as part of the manual therapy care regimen have demonstrated that the addition of manual therapy led to greater improvements in shoulder pain symptoms than exercise centered interventions or typical primary care interventions.^{3, 6, 91}

Manual Therapy at the Shoulder. Another approach to manual therapy that has been examined in patients with shoulder pain is that of applying joint mobilization or manipulation treatments solely to the glenohumeral joint or shoulder girdle articulations (acromioclavicular, sternoclavicular, scapulothoracic). Studies examining joint mobilizations targeting the glenohumeral joint compared to sham manual therapy or a control group report improvements in

pain-free shoulder range of motion and decreased sensitivity to pressure pain at the shoulder.⁸³

The addition of glenohumeral mobilization to a rehabilitation exercise regimen was also found to decrease 24-hour pain and pain during subacromial compression testing compared to the exercise regimen alone.²⁰ Manipulation techniques targeting the glenohumeral joint compared to a sham laser treatment have been reported to improve range of motion and shoulder pain ratings,² while manipulation techniques applied pragmatically to the glenohumeral, acromioclavicular joint, ribs, and/or scapula based on clinical exam also showed improvements in pain ratings and quality of pain characteristics (Short Form McGill Pain Questionnaire) in comparison to sham ultrasound treatment.⁶² These studies showed positive effects on shoulder pain through the implementation of shoulder girdle manipulation. However, they were compared only to sham modality treatments rather than other active treatment interventions, so we cannot gauge its effectiveness compared to other forms of treatment or manual therapy to the shoulder. Scapular mobilization in isolation has been compared to a sham technique and a control (no intervention) and was found to improve clinical measurements of shoulder abduction, shoulder flexion, scapular upward rotation, and patient-rated function in patients with shoulder pain.⁸² In contrast, a recent study⁹² found that patients receiving joint mobilization techniques directed at shoulder girdle joints in addition to a rehabilitation exercise and advice had no significant benefit in shoulder range of motion, functional outcome scores (Shoulder Pain and Disability Index), or self-rated change in symptoms compared to patients who received exercise and advice only. These studies found improvements in both treatment groups (rehabilitation versus rehabilitation and manual therapy), but no added benefit from joint mobilizations. It should be noted that the manual therapy techniques in these studies allowed for a large variation in the dosing and techniques applied, and while that is reflective of actual medical practice, it could have allowed

for a washing out of treatment effects due to heterogeneity of the manual interventions received by the patients.

Manual Therapy at the Spine. Joint mobilization and manipulation directed at the spine may help to improve symptoms in patients with shoulder pain.^{6, 14, 53, 61, 79} McClatchie et al. treated shoulder pain with a lateral glide mobilization technique at the lower cervical spine and reported improvements in shoulder pain ratings in comparison to a sham manual therapy technique, but failed to show any differences between groups in cervical range of motion or manual muscle testing for shoulder abduction.⁵³ A randomized controlled trial (RCT) using the addition of cervical and thoracic manipulation and mobilization techniques to the usual care regimen for treating shoulder pain used in a general practice setting has shown improved main complaint outcomes and resulted in a higher percentage of patients reporting resolution of shoulder pain symptoms at 12 and 52 week follow-up.⁶ Several single-arm trials have examined the use of thoracic spinal manipulation in the treatment of shoulder pain symptoms.^{14, 61, 79} These studies reported significant immediate and short-term improvements in shoulder pain,^{14, 79} functional outcome scores (Shoulder Pain and Disability Index),¹⁴ Global Rating of Change score,^{61, 79} and pain-free shoulder range of motion⁷⁹ following thoracic spinal manipulation. Caution should be used when attempting to establish a cause and effect relationship between thoracic manipulation and symptom improvement from these studies, as these were single-arm studies without a control group.^{14, 61, 79}

The use of mobilization and manipulation techniques to the shoulder girdle and/or spine is often used to treat patients with shoulder pain. There are still questions as to whether mobilization or manipulation techniques applied to the shoulder may have any additional benefits over comprehensive rehabilitation programs. The use of thoracic manipulation as part

of a treatment regimen for shoulder pain appears to show added benefits over traditional treatments. Single-arm trials without comparator treatments show improvements in patient-rated pain and function from thoracic manipulation as the sole form of manual therapy used to treat shoulder pain,^{14, 61, 63, 79} but there is a lack of RCTs assessing the use of thoracic manipulation to treat shoulder pain. This makes it difficult to establish a direct cause and effect relationship between thoracic manipulation and reported changes. A RCT comparing thoracic manipulation to a control group (proven intervention or placebo) would allow for cause and effect comparisons of this treatment for shoulder pain. The research contained in this dissertation will be in the form of a RCT to compare the effectiveness of thoracic manipulation to a sham thoracic manipulation.

Summary

There are kinematic synergies between the thoracic spine and the shoulder during shoulder motion to elevate the arm. It appears that differences in overall thoracic spinal motion exist between people with shoulder pain and people without shoulder pain. There may also be alterations in segmental motion at the cervicothoracic spine in people with shoulder pain or those who may develop shoulder pain when compared to those who are not bothered by shoulder pain. It has also been shown that thoracic posture affects scapular position and orientation, further linking the thoracic spine and shoulder functionally. The clinical benefits noted with thoracic spinal manipulation may be due to improvements in thoracic kinematics that carry over to improved function and reduced pain at the shoulder.

Clinical benefits from the treatment of shoulder pain with thoracic spinal manipulative therapy are becoming evident. However, the mechanisms underlying these benefits are still not well understood. One single-arm trial examined scapular kinematic and thoracic excursion measures in people with shoulder pain in response to thoracic manipulation and failed to find

significant biomechanical changes aside from a slight increase in scapular upward rotation following treatment.⁶³ However, this trial lacked a control group for comparison and also measured excursion of the trunk in relation to a global reference point rather than provide a segmental measure of the motion from the thoracic spine itself. Changes in pressure pain sensitivity are reported locally at the spine and distally in the upper extremities following cervical spinal manipulation in people with musculoskeletal pain symptoms, but pressure pain sensitivity following thoracic manipulation in people with shoulder pain has yet to be examined. Therefore, there is a need for randomized clinical trials assessing the effects of thoracic manipulation on the kinematics of the thoracic spine and shoulder as they relate to changes in pain or function of individuals with shoulder pain. There is also a need for research examining the effects of thoracic spinal manipulation on pain sensitivity measures in people with shoulder pain to determine if changes in pain processing pathways can explain the effects of thoracic SMT. Examining the mechanistic effects of thoracic spinal manipulation with respect to thoracic and shoulder kinematics and pressure pain sensitivity in their relationship to patient-rated clinical outcomes will provide valuable information as to the mechanisms underlying clinical improvements in patients with shoulder pain.

Chapter 2. Manual Therapy Directed at the Thoracic Spine and the Shoulder Girdle in Treating Subacromial Pain Syndrome: A Systematic Review

Abstract

Background: Manual therapy interventions are commonly used for musculoskeletal shoulder disorders. The purpose of this systematic review was to examine the patient-rated outcomes from randomized clinical trials (RCT) of manual therapy for patients with subacromial pain syndrome by: 1) location of treatment – shoulder girdle and/or thoracic spine, 2) type of treatment – joint mobilizations and/or manipulation techniques.

Methods: Five databases were searched for RCTs that examined patient-rated outcomes of manual therapy delivered to patients with subacromial pain syndrome. Two reviewers selected articles based on the inclusion/exclusion criteria. The articles were graded on methodological quality using the PEDro scale (0–10; ≥ 6 = high quality study). Effect sizes and 95% confidence intervals were calculated between groups for each article.

Results: Thirteen studies were included in this review, with PEDro scores ranging from 6 to 9. Of these studies, 9 studies treated the shoulder girdle only, 1 treated only the thoracic spine, and 3 treated both locations. Six of the nine studies treating only the shoulder girdle reported improved patient-rated outcomes with the use of manual therapy (effect sizes = 0.34-1.66), and all 4 studies treating the thoracic spine alone or in combination with the shoulder girdle showed improved outcomes (effect sizes = 0.34-0.61). With respect to treatment type, 8 studies used mobilization only, 2 used manipulation only, and 3 used a combination of mobilization and

manipulation. Six of the eight mobilization only studies reported improved patient-rated outcomes (effect sizes = 0.34-1.66), 1 of the 2 studies using only manipulation reported positive benefits (effect size = 0.58), and all 3 studies utilizing a combination of mobilization and manipulation techniques had positive benefits (effect sizes = 0.36-0.61).

Conclusion: Overall, it appears that a combination of mobilization and manipulation techniques applied to the thoracic spine with or without shoulder manual therapy increase the likelihood produce positive patient-rated outcomes. Manual techniques to the shoulder girdle only do not appear to be consistently beneficial. Studies that used both mobilization and manipulation techniques consistently showed beneficial results in treating subacromial pain syndrome. However, no clear conclusion could be established for the sole use of mobilization or manipulation techniques alone.

Key Words: impingement syndrome, subacromial impingement syndrome, shoulder manual therapy, shoulder mobilization, shoulder manipulation

INTRODUCTION

Manual therapy interventions are commonly used by healthcare providers to treat the symptoms and impairments associated with shoulder pain. Techniques applied to soft tissues and joint structures to modulate pain, improve joint motion, facilitate movement, and improve patient-rated outcomes.^{14, 19, 26} Manual therapy interventions for shoulder pain are often delivered directly to the painful shoulder and/or the thoracic spine (thoracic spine, cervicothoracic junction, and ribs) with either a non-thrust manipulation (mobilization) or thrust manipulation (manipulation) technique or combination of the two types. Beneficial clinical outcomes have been reported with the use of shoulder or spinal techniques or a combined approach of manual therapy for musculoskeletal shoulder pain.^{1, 2, 4, 5, 8, 21, 31-33, 35} Single-arm trials have reported positive benefits from the use of thoracic spinal manipulation as the sole manual technique to treat the shoulder.^{8, 31} It is unclear if a specific type (mobilization and/or manipulation) or application site (the shoulder girdle and/or the thoracic spine) may provide superior benefits.

Mobilization (non-thrust manipulation) is a low velocity, oscillatory movement applied across a joint in any part of the joint range of motion and performed with small or large amplitudes.^{14, 19} A manipulation technique is a high-velocity, low amplitude thrust performed at the end of available joint motion.¹⁹ Mobilization or manipulation techniques can be applied to the shoulder girdle – glenohumeral, sternoclavicular, acromioclavicular and scapulothoracic joints – to address shoulder pain or restricted shoulder girdle motion. A model of regional interdependence³⁴ postulates that impairments at anatomical segments proximal or distal to the affected region may contribute to the patient's primary complaint. Applying this model to shoulder pain indicates the examination of the interdependent axial skeleton (the thoracic spine

and ribs) in addition to the shoulder. Manual therapy techniques applied to the spine or ribs has been classically based on improving thoracic spine motion to attain full shoulder motion.

Alternatively, manual therapy techniques applied to the spine may reduce the symptoms of musculoskeletal pain by stimulating neurophysiological responses at the peripheral and/or central nervous system that affect pain processing, as well as produce responses within the motor control system that alter muscle activity and reflex responses.^{6, 18, 27}

Subacromial impingement syndrome is a common shoulder diagnosis that may encompass a broad range of tissue pathologies.^{9, 23, 25} However, the term shoulder “impingement” refers to a mechanism of compression, which may not consistently be the case. The term “subacromial pain syndrome” is an appropriate term that indicates shoulder pain located at the subacromial region, without reference to pathology or mechanism.

Two prior systematic reviews of randomized controlled trials (RCTs)^{13, 20} have reported that manual therapy combined with therapeutic exercise is an effective treatment intervention for subacromial pain syndrome. These reviews noted limited evidence due to a small number of high quality studies, a lack of standardized treatment regimens, and a lack of long-term follow-up. Two recent systematic reviews of RCTs^{10, 11} evaluated evidence for manual therapy for the treatment of musculoskeletal shoulder pain. Camarinos et al.¹¹ looked specifically at the use of glenohumeral mobilizations and/or manipulation, and concluded that there was a trend of reduced shoulder pain.¹¹ However, definitive conclusions could not be made regarding the effects of glenohumeral manual therapy on shoulder function, quality of life, or differences in effects for mobilization and manipulation.¹¹ Brudvig et al.¹⁰ in a systematic review found inconclusive evidence for the benefit of therapeutic exercise combined with manual therapy over therapeutic exercise alone for shoulder pain, and concluded more high quality studies are needed.

Only one of the systematic reviews examined the effects of manual therapy applied to a specific location (glenohumeral joint only),¹¹ and none examined patient-rated outcomes based on location of treatment (shoulder girdle joints versus spine) or how the manual therapy was delivered (manipulation versus mobilization).

The purpose of this systematic review was to examine the evidence from RCTs of joint mobilization and manipulation techniques delivered to the thoracic spine (thoracic spine, cervicothoracic junction, and ribs) and shoulder girdle (glenohumeral, acromioclavicular, and sternoclavicular joints) in adults with symptoms of subacromial pain syndrome to characterize the effects on patient-rated outcomes for: 1) location of the manual techniques (shoulder girdle and/or the thoracic spine) and 2) type of technique (mobilization and/or manipulation). The results of this study will further the understanding of the efficacy of manual therapy on patient-rated outcomes of pain and function/ disability in patients with subacromial pain syndrome based on treatment location (shoulder and/or thoracic spine) and type (manipulation and/or mobilization) of manual intervention.

METHODS

The databases used for this literature search were PubMed, CINAHL, Cochrane Central Register of Controlled Trials (CENTRAL), SPORTDiscuss, and Web of Science. Three separate searches were conducted in each database using the following search terms: Search 1 = “shoulder” AND “manual therapy”, Search 2 = “shoulder” AND “mobilization”, Search 3 = “shoulder” AND “manipulation”. Where filters were available, articles were filtered to include only research articles, only English language articles, and articles using only human subjects. Search strategies were kept intentionally broad in order to minimize the risk of inadvertently excluding relevant articles.

Inclusion and Exclusion criteria

Only RCTs were included to provide high level evidence for clinical treatment-decision making.¹⁵ RCTs of manual therapy directed at the thoracic spine or shoulder girdle in adults were considered. The condition of interest was shoulder pain of any duration related to subacromial pain syndrome, that include impingement syndrome, subacromial bursitis, rotator cuff disease, rotator cuff tears (partial-thickness), and rotator cuff tendinopathy. Articles were excluded if the study population included non-musculoskeletal pain, systemic disease, complete rotator cuff tears, shoulder pain of cervical or neurological origin, shoulder pain due to fractures, shoulder dislocation or subluxation, surgical interventions about the shoulder, myofascial symptoms, adhesive capsulitis, or restricted shoulder range of motion.

The interventions of interest were manual therapy of the thoracic spine or shoulder girdle to include mobilization of low or high grade or manipulation techniques. All participants must have received manual therapy to the shoulder girdle or thoracic spine. Studies in which manual therapy was delivered to multiple joints and regions were included, as long as all participants received manual therapy to the thoracic spine or shoulder girdle. Studies were excluded if it was not clear if participants received at least one form of manual therapy targeting the thoracic spine or shoulder girdle. The outcomes of interest were patient-rated outcomes of pain or function/disability. Studies containing only measures of economics or credibility of sham comparator interventions were excluded. Study results published only as abstracts were also excluded. Only studies that were published in English in peer reviewed journals were included, the gray literature was not searched for this review.

Review Process

The searches were performed in each database, producing 15 separate search results. Two reviewers (JK and MT) independently examined the titles and abstracts from each search to identify articles for full text review based on the inclusion and exclusion criteria. Articles that did not fit the criteria of this review based on title or abstract were excluded, while articles that appeared to match the review criteria or were ambiguous in their title or abstract were selected for full text review so as not to exclude relevant articles. The results from each of the searches were compiled, and duplicate titles were removed. The selected full texts were scrutinized independently by both reviewers according to the inclusion and exclusion criteria for this review and appropriate articles were identified for inclusion. Any disagreement was discussed between the reviewers and resolved; a third reviewer was consulted in a tie, when necessary.

Methodological Quality Assessment

Each article included in this review was assessed by two reviewers (JK and MT) using the PEDro (Physiotherapy Evidence Database) scale. The PEDro scale is an 11-question quality assessment for RCTs, with very good inter-rater reliability (ICC=0.68).¹⁷ The questions are scored either '0' or '1' as to whether the study met each of the specified quality criteria (0 for not meeting the quality criterion, 1 for meeting the quality criterion). The first question is used to assess the external validity of a study and is not used in the score. Therefore, the PEDro score is calculated from the remaining 10 questions and can range from 0 to 10. A score of ≥ 6 on the PEDro scale has been suggested as a cut point to designate high quality studies.^{11, 17} When an item was not addressed specifically within an article, it was recorded as a 0 score. The reviewers discussed the PEDro scale and its components prior to rating any articles. Disagreements

between the reviewers in a scored item were discussed and resolved; there was no need for a third reviewer to resolve any disagreements.

Data extraction

Data from patient-rated outcomes of pain or function/disability variables were used for analysis. Reviewers agreed upon the data to be extracted from the studies, and data extraction was done following inclusion and scoring of an article. The mean difference between groups, 95% confidence interval (95% CI) on the difference, and effect size were calculated for the pain and function/disability outcomes using the equation:

$$d = \frac{\bar{X}_1 - \bar{X}_2}{\left(\frac{S_1^2 + S_2^2}{2} \right)^{1/2}}$$

Where d = effect size, \bar{X}_1 and \bar{X}_2 are the group means, and s_1 and s_2 are the group standard deviation.²⁸

RESULTS

Search results and the number of articles retained for this review are represented in Figure 1. A total of 2,188 titles and abstracts were reviewed from the search results. Once appropriate articles were identified from the title and abstract review, duplicate articles were removed. After the full text review, 13 articles were retained.

Participant Characteristics

The population samples varied across studies by age (Table 1). The duration of symptoms varied between studies; several studies^{1, 3, 12, 22, 29, 30} did not report the duration of participant symptoms, 2 studies had participants with average duration of symptoms less than 3 months,^{5, 35} while 5 studies had an average duration of symptoms among participants of greater than 3 months.^{2, 4, 7, 16, 36} Yiasemides et al.³⁶ reported a significantly greater duration of

symptoms ($p < 0.05$) in the control group (22, 95% CI [12.1, 32.8] months) than the experimental group (9.7, 95% CI [6.3, 13.1] months).

Interventions

For the location of manual therapy, 9 of the studies treated the shoulder girdle only,^{1, 3, 7, 12, 16, 22, 29, 30, 36} 1 treated only the thoracic spine and axial skeleton,⁵ and 3 treated both regions.^{2, 4, 35} For the type of treatment technique, 8 studies used mobilization only,^{3, 4, 7, 12, 16, 29, 30, 36} while 2 of the studies used manipulation only,^{1, 22} and 3 used a combination of mobilization and manipulation techniques.^{2, 5, 35} Both of the studies that used manipulation only as the type of treatment technique, manipulated only the shoulder girdle joints. Manipulation of the thoracic spine was not used as the sole manual therapy intervention in any of the studies. Of note, 2 of the 3 studies treating both the thoracic and shoulder regions were also the same studies that combined both manipulation and mobilization techniques. Of the 9 studies that used only mobilization techniques, all but 1 applied the manual techniques to the shoulder only. Tables 2-6 show the location and type of manual therapy intervention used in the studies, as well as comparator treatment or control.

Quality Assessment

Two reviewers (JK and MT) scored each of the articles independently using the PEDro scale. Any disagreement in a scored item between the two reviewers was discussed and resolved; there was no need for a third reviewer to resolve any disagreements. All of the articles had a PEDro score of 6 or greater. The scores ranged from 6 to 9, with a mean of 7.3 across all of the studies included in this review (Table 7).

Outcome Variables

The patient-rated outcome variables for each included study are listed in Table 8. Eleven studies used patient-rated pain measures in the form of a visual analog scale (VAS), numeric pain rating scale (NPRS), or the Short-Form McGill Pain Questionnaire (SFMPQ). Eight studies used one or more patient-rated outcome measures of function/disability,^{2-5, 30, 35, 36} one of which was a self-developed non-validated measure.² Statistical outcomes for dependent variables are shown in Tables 9-10 and Figures 2-3.

Effect Sizes

Effect sizes can assess the robustness of study results, with 0.2 representing a small effect, 0.5 medium effect, and 0.8 a large effect.²⁴ Effect sizes could be calculated from data provided in 12 of 13 studies. Effect sizes for studies that showed added benefit from manual therapy intervention (10 of 13 studies) ranged from 0.34 – 1.29 for pain measures and 0.34 - 1.66 for function/disability outcomes^{2-5, 7, 12, 22, 29, 35} (Tables 9 – 10) for dependent measures that had significant changes. The following effect sizes were calculated from the studies that showed added benefit from manual therapy and came from 9 measures from 6 of the 11 studies that reported pain and 5 measures from 4 of the 8 studies that reported function/disability. For studies that used manual therapy techniques directed at the shoulder girdle only, effect sizes ranged from 0.34-1.29 for pain measures and 0.61-1.66 for function/disability measures for measures that showed added benefit^{7, 12, 29} (Table 9 & 10). The study that used manual therapy for axial skeleton only⁵ (cervical and thoracic spine and ribs) had an effect size of 0.39 for pain measures at 12 weeks and 0.36 for function/disability measures at 26 weeks, reflecting significant changes at only 1 out of 4 time points for each of these variables. Only 1 study² out of the 3 studies^{2, 4, 35} that used manual techniques directed toward both the shoulder girdle and

the thoracic spine showed a positive effect on pain, with an effect size of 0.61 (1 out of 3 measures). The effect sizes for function/disability measures where added benefit from manual therapy was seen from treatment of both the thoracic spine and shoulder ranged from 0.34-0.59 (2 out of 4 measures) in 2 studies.^{2, 4} The effect sizes in studies where no significant differences in patient-rated outcomes between the manual therapy and comparator groups had effect sizes that ranged from -0.23 to 0.41.^{1, 16, 35, 36} These effect sizes for non-significant findings were seen in 9 measures in 5 of the 11 studies reporting pain (Table 9) and 8 measures in 4 of the 8 studies reporting function/disability outcomes (Table 10). One study,³⁰ did not provide mean and standard deviation data for pain or function/disability measures (2 measurement intervals for each), so effect sizes could not be calculated for the data from that study.

In studies that utilized mobilization techniques only, the effect size for pain measures ranged from 0.34-1.29 for measures with added benefit,^{7, 12, 29} while the effect size for function/disability measure ranged from 0.34-1.66 for measures with added benefit.^{3, 4} The study of manipulation only (shoulder girdle only) that showed benefit had an effect size of 0.58 in the pain measures.²² The 3 studies that used both manipulation and mobilization techniques had effect sizes ranging from 0.39-0.61 for pain (across 3 of 7 measures) when there was added benefit from manual therapy, and 0.36-0.59 for function/disability measures (across 3 of 7) for added effect.^{2, 5, 35} Based on these results, the large effects (≥ 0.80) for pain and function/disability patient-rated outcomes were found for studies that treated the shoulder only, using only mobilization techniques.^{3, 7, 12} Effect sizes from the remainder of the studies that showed positive benefits from mobilization to the shoulder only were moderate (0.34-0.49).^{29, 30} Studies mobilizing the shoulder only that did not show any added benefits from manual therapy had effects ranging from -0.05-0.28.^{16, 36}

DISCUSSION

This systematic review of manual therapy interventions for patients with subacromial pain syndrome indicates that manual therapy interventions that included treatment of both the thoracic spine and the shoulder may have added benefits for patient-rated outcomes, and while the treatment directed solely at the spine may yield some benefit, it may be limited. Treatment of the thoracic spine (with or without treatment of the shoulder girdle) showed beneficial effects in patient-rated outcomes in 3 of 4 studies, with medium effect sizes (0.34 – 0.61). Only 38% of the measures taken actually showed added benefit, while the remainder were not significant. The studies that treated the shoulder in addition to the thoracic spine (3 studies)^{2, 4, 35} showed added benefit in 43% of pain and function/disability measures, while the single study that treated the spine only⁵ showed added benefit in 25% of the pain and function/disability measures. Therefore, this small sample of studies suggests that manual therapy targeting both the shoulder and the spine may have a moderate added benefit, but treating the spine only may have more limited benefits. Of the 13 RCTs, treatment was predominately directed at the shoulder girdle only (9 studies), and with mobilization techniques only (8 studies). Inconsistent results were found when the shoulder girdle was the only region treated, and when mobilization or manipulation techniques were used in isolation.

Overall, it appears that a combination of techniques (mobilization and manipulation) applied to the thoracic spine in combination with manual therapy techniques to the shoulder may be more likely to produce positive patient-rated outcomes. Our results indicate that a combination of techniques directed at the shoulder girdle and spine or spine only showed benefits (with medium effect sizes) in patient-rated outcomes while those studies that used *either* manipulation or mobilization techniques did not all show benefit. These results were primarily

supported by 3 studies that incorporated treatment of the thoracic spine using both manual therapy techniques in a pragmatic manner (treatment application as deemed appropriate by the clinician).^{2, 5, 35} Manual techniques to the shoulder girdle only do not appear to be consistently beneficial. The studies with the largest effect sizes treated only the shoulder, but they also had among the smallest sample sizes.^{3, 7, 12} In the single study where mobilization and manipulation techniques were applied only to the spine, there was added benefit at only 1 of 3 long-term measures (at 12 weeks for pain and at 26 weeks for function/disability) and not at the short-term measure (6 week) for both pain and function/disability (Table 10). Therefore, even though this study did show an added benefit from manual therapy, the majority of pain and function/disability measures in this study showed no added benefit from manual therapy.

Since all studies in this review met the threshold for high quality studies (PEDro score ≥ 6), we assessed the weight of evidence largely by the number of trials that indicated added benefits versus no added benefits from joint mobilization/manipulation and the effect sizes of the benefits. While 6 studies^{2, 3, 7, 12, 22, 29} reported consistently significant benefits in pain and function/disability from manual therapy, 3 of the studies in this review^{4, 5, 30} had both significant and non-significant findings, and 4 studies^{1, 16, 35, 36} reported only non-significant findings with respect to patient-rated pain and function. Across the 13 studies included in this review 9 of 18 pain measures and 6 of 16 function/disability measures showed significant benefit from manual therapy to the shoulder and/or thoracic spine for the treatment of subacromial shoulder pain. Therefore, there were more non-significant outcome measures than positive outcome measures across the studies, even though the majority of studies reported benefits in at least one pain or function/disability measure.

Six^{3, 7, 12, 22, 29, 30} of nine^{1, 3, 7, 12, 16, 22, 29, 30, 36} studies using manual therapy interventions applied to the shoulder girdle alone reported added benefit with respect to patient-rated outcomes. The glenohumeral joint was treated in all of these studies. The studies that showed added benefits from manual therapy to the shoulder girdle demonstrated short-term effects (4 weeks or less), and did not assess long-term effects. However, in two studies which indicated benefits of manual therapy^{22, 29} the 95% confidence interval of the mean difference between groups had a range that included values that would indicate no difference or a difference that could favor the comparator group. Therefore, they may be more accurately classified as not having shown a benefit with manual therapy directed at the shoulder girdle. Overall, this indicates that 4 studies^{3, 7, 12, 30} found positive changes in patient-rated outcomes for manual therapy directed at the shoulder over comparator treatment, while 5 studies^{1, 16, 22, 29, 36} found no added benefit. The largest effects (1.29-1.66) were seen in the 2 studies with n=7 participants per group,^{3, 12} so it is possible that these are artificially inflated and lack generalizability due to their small sample size.

No RCT examined the effects of manual therapy treatment to the thoracic spine alone. One study⁵ did, however, examine the effects of manual treatment at the cervical and thoracic spine and reported positive benefits with medium effect sizes (0.36-0.39), but as previously noted, these positive effects were seen in only 1 of 4 pain measures (12 weeks) and 1 of 4 function/disability measures (26 weeks). Generally, manual therapy interventions that included treatment of the thoracic spine with manipulation and/or mobilization showed better patient-rated outcomes as compared to groups that received no manual therapy as part of their treatment. While two studies^{2, 5} out of 3 that included treatment of the thoracic spine using a combination of techniques found significantly greater improvement with manual therapy, the study that treated

the shoulder and thoracic spine with mobilization techniques only⁴ found statistically significant improvement (at 22 week follow-up) that did not reach the threshold of minimal clinically important difference for the functional scale used. The two studies reporting positive effects incorporated both mobilization and manipulation techniques used a pragmatic approach and saw benefits at follow-up periods ranging from 2-6 months. Overall, the results from these studies suggest that mobilization and/or manipulation of the thoracic spine in addition to the shoulder when treating subacromial pain syndrome may have added benefit, but the benefits over the comparator group were not large in magnitude. No studies directly compared manual therapy directed at the shoulder versus the spine, or mobilizations versus manipulations.

The use of mobilization techniques alone was not conclusively beneficial in 8 studies,^{3, 4, 7, 12, 16, 29, 30, 36} with only 6 studies reporting a beneficial outcome.^{3, 7, 12, 29, 30} When manipulation was used as the sole treatment technique, and applied to the shoulder girdle only, there were equivocal reported results in patient-rated outcomes in 2 studies.^{1, 22} Of note in the studies that used manipulation techniques at the shoulder, the study that treated only the glenohumeral joint¹ reported no difference in patient-rated pain compared to sham treatment (laser), while the study that treated the glenohumeral, acromioclavicular, and/or sternoclavicular joints²² found improvements in pain measures compared to sham treatment (ultrasound). Of the 4 studies that reported no added benefit from mobilization, 1 had the oldest average age of participants (≥ 60 years) of studies included within this review.³⁶ This may be an indication that older patients are less likely to benefit from glenohumeral mobilization techniques. No study provided a direct comparison of mobilization to manipulation.

Three of the studies included in this review had small sample sizes, ranging from $n=7$ to $n=9$ per group.^{3, 12, 16} While one of these studies was designated as a pilot study, the other two

were not. Our inclusion/exclusion criteria did not include sample size requirements, so these studies were included. Both Conroy et al. and Barbosa et al. reported improvements in patient-rated pain and function, respectively, but each had total sample size of n=14.^{3, 12} Kachingwe et al. had an overall sample size of n=33, divided among 4 groups (n=7-9/ group).¹⁶ The small sample size of these studies decreases their generalizability, as they may not represent the spectrum of patients with subacromial pain syndrome. Two of these small studies also showed the greatest effect sizes favoring treatment of the shoulder girdle with mobilization,^{3, 12} and this may have led to artificially high effect size associated with this location and technique. Since this review is limited to patient-rated outcomes, we did not consider findings such as range of motion measurements, strength, or algometry measurements.

Limitations

A meta-analysis was not performed because there was inconsistent use of patient-rated pain and functional/disability outcome scales across studies. While the NPRS and VAS were commonly used, some studies used either a summation of VAS values² or point scales deviating from the typical 10-point or 10 cm (100mm) scales.^{5, 35} There were also several different function/disability questionnaires used, which again limited the ability to collapse data across studies.

No studies in this review made direct comparisons of location (shoulder versus thoracic spine) or type (mobilization versus manipulation) of manual therapy intervention. We also did not attempt to separate studies based on whether a standardized dosing of manual therapy was utilized versus a pragmatic approach in the delivery of manual therapy treatment. Studies were not excluded for utilizing manual techniques at joints other than those of the thoracic spine or shoulder girdle. Six of the thirteen studies applied the respective manual techniques at

additional regions; 2 included scapular mobilization³⁶ or manipulation²² and all 4 of the studies that utilized manual therapy techniques applied to the thoracic spine also could have included treatment at the cervical spine as well.^{2, 4, 5, 35} The dosing of manual therapy varied between the studies, some of the studies used manual therapy in isolation while others used other interventions in addition to manual therapy (see Tables 3-5), and 3 of the studies^{1, 4, 22} used sham comparators while others used various treatment interventions as comparators (Table 6). Therefore, the heterogeneity in the application of manual therapy and among comparator groups could have affected the size of treatment differences. The small sample size within the 2 studies with the largest effect size may have led to artificially inflated effect sizes by chance. The fact that there were only 4 studies in this review where treatment was directed at the thoracic spine (3 in combination with the shoulder, and 1 where only the cervical and thoracic axial skeleton were treated) means that results and conclusions drawn regarding the benefits of treating the thoracic spine are from a relatively limited number of studies.

Conclusions

The results of this review indicate that treating subacromial pain syndrome with a combination of joint mobilization and manipulation techniques that include treatment of the shoulder and thoracic spine may be the most likely to produce positive patient-rated outcomes. Results from studies treating the shoulder girdle alone were less consistently beneficial. No clear conclusions can be drawn whether mobilization or manipulation is consistently beneficial in the treatment of subacromial pain syndrome. However, studies that utilized both mobilization and manipulation more often reported positive results in patient based outcomes with medium effect sizes. The 13 RCTs in this review were considered high quality.

Future Research

The number of studies included in this review may not represent a large enough sample to draw definitive conclusions regarding which location or type of manual therapy may provide the best results in patients with subacromial pain. A greater number of RCTs assessing treatment of the thoracic spine in patients with subacromial pain is needed to strengthen any conclusions on clinical benefits from its use. Future studies examining treatment effects based on location (spine, shoulder, or both), or based on type of manual therapy modality (mobilization, manipulation, or both) would provide evidence as to whether there is an effect of treatment location or type when treating shoulder pain. The use of a standardized treatment regimen or pragmatic approach may also warrant evaluation when assessing the effects of manual therapy location or type for treating shoulder pain.

References

1. Atkinson M, Mathews R, Brantingham JW, et al. A randomized controlled trial to assess the efficacy of shoulder manipulation vs. placebo in the treatment of shoulder pain due to rotator cuff tendinopathy. *J Am Chiropractic Assoc.* 2008;45:11-26.
2. 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.
3. Barbosa RI, Goes R, Mazzer N, Fonseca MCR. The influence of joint mobilization on tendinopathy of the biceps brachii and supraspinatus muscles. *Rev Bras Fisioter.* 2008;12:298-303.
4. Bennell K, Wee E, Coburn S, et al. Efficacy of standardised manual therapy and home exercise programme for chronic rotator cuff disease: randomised placebo controlled trial. *BMJ.* 2010; DOI 10.1136/bmj.c2756.
5. 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.
6. 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.
7. Bialoszewski D, Zaborowski G. Usefulness of manual therapy in the rehabilitation of patients with chronic rotator cuff injuries. Preliminary report. *Ortop Traumatol Rehabil.* 2011;13:9-20.

8. 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.
9. Braman JP, Zhao KD, Lawrence RL, Harrison AK, Ludewig PM. Shoulder impingement revisited: evolution of diagnostic understanding in orthopedic surgery and physical therapy. *Med Biol Eng Comput.* 2013; DOI 10.1007/s11517-013-1074-1
10. Brudvig TJ, Kulkarni H, Shah S. The effect of therapeutic exercise and mobilization on patients with shoulder dysfunction: a systematic review with meta-analysis. *J Orthop Sports Phys Ther.* 2011;41:734-748.
11. Camarinos J, Marinko L. Effectiveness of manual physical therapy for painful shoulder conditions: a systematic review. *J Man Manip Ther.* 2009;17:206-215.
12. Conroy DE, Hayes KW. The effect of joint mobilization as a component of comprehensive treatment for primary shoulder impingement syndrome. *J Orthop Sports Phys Ther.* 1998;28:3-14.
13. Desmeules F, Cote CH, Fremont P. Therapeutic exercise and orthopedic manual therapy for impingement syndrome: a systematic review. *Clin J Sport Med.* 2003;13:176-182.
14. Greenman PE. *Principles of manual medicine.* 2nd. Baltimore: Williams & Wilkins; 1996.
15. Guyatt G, Rennie D, Evidence-Based Medicine Working Group., American Medical Association. *Users' guides to the medical literature : a manual for evidence-based clinical practice.* Chicago, IL: AMA Press; 2002.

16. Kachingwe AF, Phillips B, Sletten E, Plunkett SW. Comparison of manual therapy techniques with therapeutic exercise in the treatment of shoulder impingement: a randomized controlled pilot clinical trial. *J Man Manip Ther*. 2008;16:238-247.
17. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther*. 2003;83:713-721.
18. Maigne JY, Vautravers P. Mechanism of action of spinal manipulative therapy. *Joint Bone Spine*. 2003;70:336-341.
19. Maitland GD. *Maitland's Vertebral Manipulation*. 7th. New York: Elsevier; 2005.
20. Michener LA, Walsworth MK, Burnet EN. Effectiveness of rehabilitation for patients with subacromial impingement syndrome: a systematic review. *J Hand Ther*. 2004;17:152-164.
21. Mintken PE, Cleland JA, Carpenter KJ, Bieniek ML, Keirns M, Whitman JM. Some factors predict successful short-term outcomes in individuals with shoulder pain receiving cervicothoracic manipulation: a single-arm trial. *Phys Ther*. 2010;90:26-42.
22. Munday SL, Jones A, Brantingham JW, Globe G, Jensen M, Price JL. A randomized, single-blinded, placebo-controlled trial to evaluate the efficacy of chiropractic shoulder girdle adjustment in the treatment of shoulder impingement syndrome. *J Am Chiropractic Assoc*. 2007;44:6-15.
23. Neer CS, 2nd. Impingement lesions. *Clin Orthop Relat Res*. 1983;70-77.
24. Norman GR, Wyrwich KW, Patrick DL. The mathematical relationship among different forms of responsiveness coefficients. *Qual Life Res*. 2007;16:815-822.

25. Papadonikolakis A, McKenna M, Warne W, Martin BI, Matsen FA, 3rd. Published evidence relevant to the diagnosis of impingement syndrome of the shoulder. *J Bone Joint Surg Am.* 2011;93:1827-1832.
26. Paris SV. A history of manipulative therapy through the ages and up to the current controversy in the United States. *Journal of Manual and Manipulative Therapy.* 2000;8:66-77.
27. Pickar JG. Neurophysiological effects of spinal manipulation. *Spine J.* 2002;2:357-371.
28. Portney LG, Watkins MP. *Foundations of clinical research : applications to practice.* Norwalk, Conn.: Appleton & Lange; 1993;652-653.
29. Senbursa G, Baltaci G, Atay A. Comparison of conservative treatment with and without manual physical therapy for patients with shoulder impingement syndrome: a prospective, randomized clinical trial. *Knee Surg Sport Tr A.* 2007;15:915-921.
30. Senbursa G, Baltaci G, Atay OA. The effectiveness of manual therapy in supraspinatus tendinopathy. *Acta Orthop Traumatol Turc.* 2011;45:162-167.
31. 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.
32. Surenkok O, Aytar A, Baltaci G. Acute effects of scapular mobilization in shoulder dysfunction: a double-blind randomized placebo-controlled trial. *J Sport Rehabil.* 2009;18:493-501.
33. Teys P, Bisset L, Vicenzino B. The initial effects of a Mulligan's mobilization with movement technique on range of movement and pressure pain threshold in pain-limited shoulders. *Man Ther.* 2008;13:37-42.

34. Wainner RS, Whitman JM, Cleland JA, Flynn TW. Regional interdependence: a musculoskeletal examination model whose time has come. *J Orthop Sports Phys Ther.* 2007;37:658-660.
35. 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.
36. Yiasemides R, Halaki M, Cathers I, Ginn KA. Does passive mobilization of shoulder region joints provide additional benefit over advice and exercise alone for people who have shoulder pain and minimal movement restriction? A randomized controlled trial. *Phys Ther.* 2011;91:178-189.

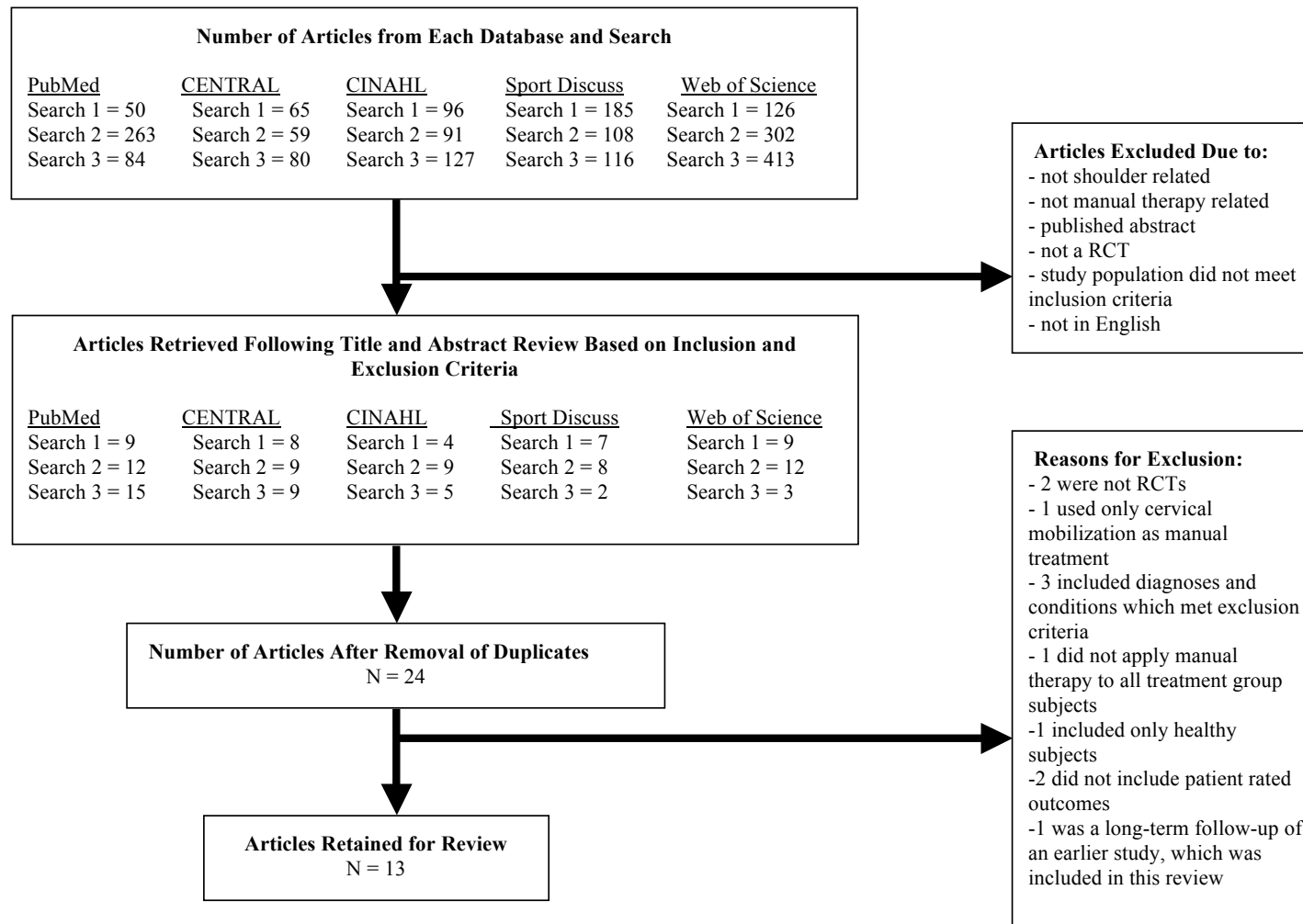


Figure 1. Search Results

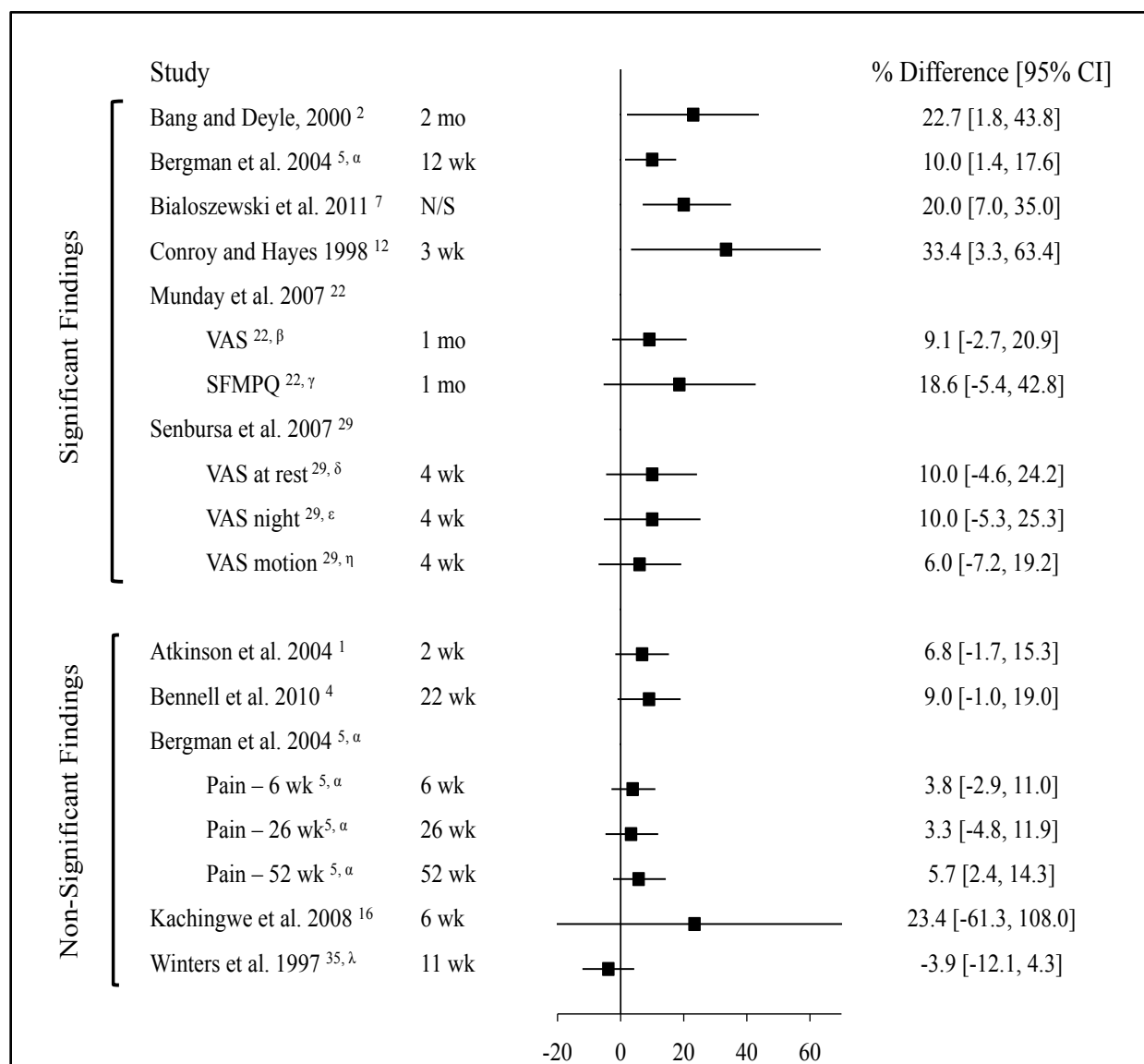


Figure 2. Forest Plot for Patient-rated Pain. Percent difference in pain outcomes between manual therapy and comparator groups. Positive value favors manual therapy group. Percent difference is based on numeric pain rating scale (NPRS) or visual analog scale (VAS) results, except as noted below.

α = 21-point numeric pain scale

β = VAS for pain

γ = Short-Form McGill Pain Questionnaire (SFMPQ)

δ = VAS for pain at rest

ϵ = VAS for night pain

η = VAS for pain with motion

λ = 28-point numeric pain scale, synovial group

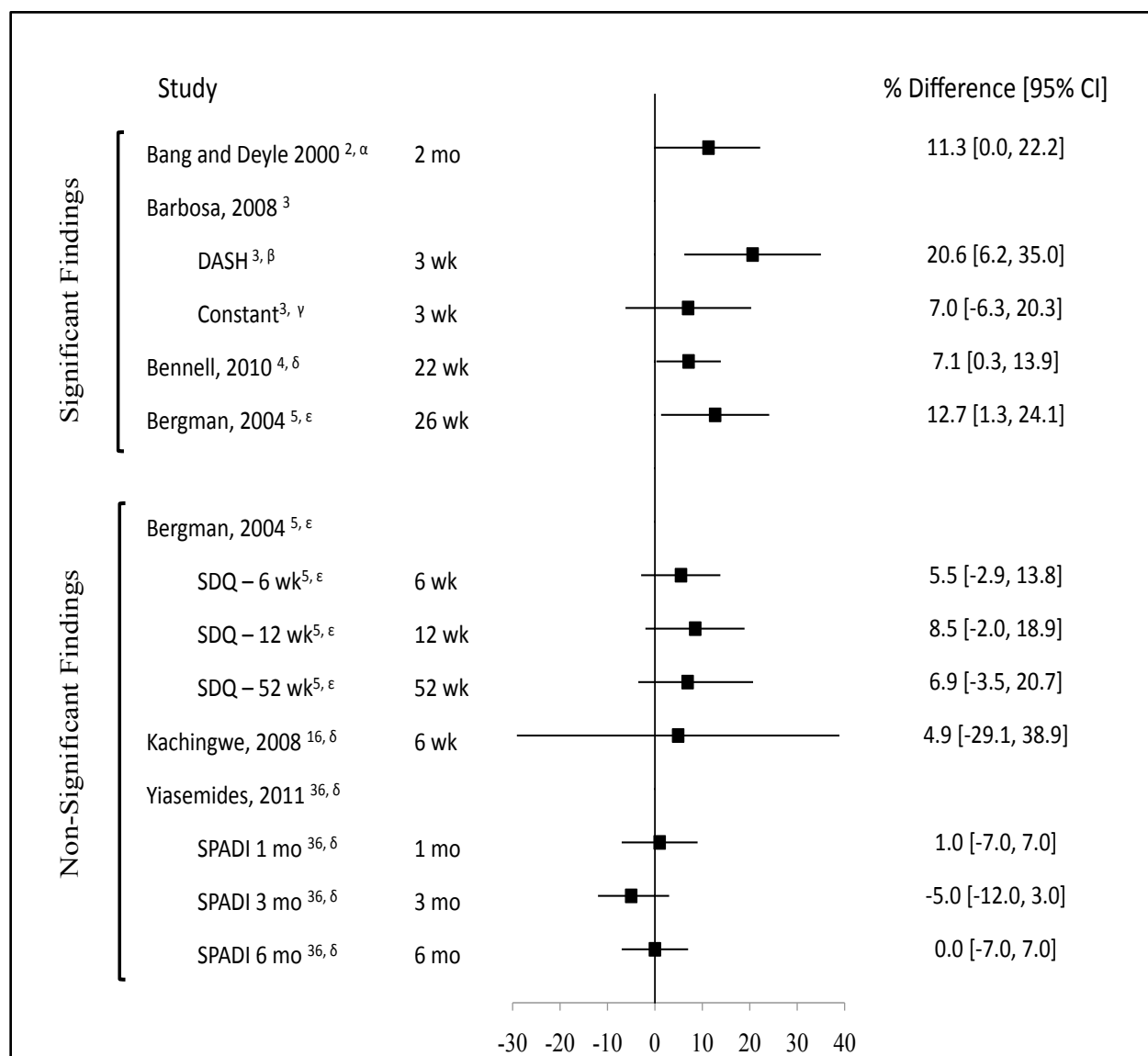


Figure 3. Forest Plot for Function/Disability. Percent difference in function/disability outcomes between manual therapy and comparator groups. Positive value favors manual therapy group.

α = Self-developed functional questionnaire

β = Disability of the Arm and Shoulder (DASH)

γ = Constant Questionnaire

δ = Shoulder Pain and Disability Index (SPADI)

ϵ = Shoulder Disability Questionnaire (SDQ)

Table 1. Participant Characteristics by Study

AC = acromioclavicular, GH = glenohumeral, SC = sternoclavicular, RC = rotator cuff, NPRS = numeric pain rating scale, ROM = range of motion, TTP = tenderness to palpation, N/S = no stated within the manuscript

* synovial group from Winters et al.³⁵ was included within this review as it was the subgroups within that study which met the inclusion criteria

Study	Manual Therapy Group			Comparator Group			Inclusion Criteria	Exclusion Criteria
	Sample Size	Age (years)	Duration of Symptoms	Sample Size	Age (years)	Duration of Symptoms		
Atkinson et al. 2008 ¹	30	41.53 (range 18-63)	N/S	30	42.0 (range 20-76)	N/S	rotator cuff tendinopathy; 3 of 4 criteria present: 1) tender to palpation (TTP) over the greater tuberosity, 2) tenderness along the anterior edge of the acromion, 3) painful arc of abduction between 60-120°, 4) positive empty can test	Traumatic dislocation, instability, positive drop arm test, pain radiating distal to the elbow, shoulder surgery within 2 years, cardiac/ pulmonary/ systemic disease, referred pain to the shoulder, osteoarthritis, no dysfunction of the GH or AC joint per Shafer and Faye technique
Bang and Deyle 2000 ²	28	42 (SD 10.1)	5.6 (SD 3.7) months	24	45 (SD 8.4)	4.4 (SD 2.8) months	Between 18 and 65 years of age, painful with overpressure into shoulder flexion or passive internal rotation at 90° shoulder flexion, pain with active shoulder abduction or with resisted break tests (abduction, internal rotation, or external rotation)	Change in medication within 2 weeks prior to study, any form of treatment outside the study, pending litigation over injury, RC tear or adhesive capsulitis, history of dislocation/ subluxation/ fracture, cervical radiculopathy, history of cervical/ shoulder/ back surgery, systemic or neurological disease, physical therapy or chiropractic treatment of the shoulder/ neck/

								upper back, insufficient English to comprehend explanations and respond to questions
Barbosa et al. 2008 ³	7	43.57 (SD 7.59)	N/S	7	48.71 (SD 7.27)	N/S	Supraspinatus and/or biceps brachii tendinitis; TTP of the supraspinatus and/or biceps tendon, positive Jobe/ Speed/ Yergason test	Complete rupture of RC tendon or imaging revealing calcific tendonitis
Bennell et al. 2010 ⁴	59	59.3 (SD 10.1)	Median 24 months (interquartile range 6-54)	61	60.8 (SD 12.4)	Median 14 months (interquartile range 6-24)	Diagnosis of RC disease, >18 years of age, shoulder pain >3 months, pain severity >3/10 on NPRS, pain with abduction or external rotation, positive impingement test	Shoulder pain >7/10 at rest, suspicion of complete RC tear, previous shoulder surgery, osteoarthritis of the shoulder on radiographs, previous fracture, systemic disease, more than 50% restriction of passive ROM in two or more planes, referred pain from vertebral structures, complex region pain syndrome, active intervention in the previous three months, anti-inflammatory drugs in the past two weeks, inability to understand English
Bergman et al. 2004 ⁵	79	48.4 (SD 12.4)	< 6 weeks – 28 6 weeks – 25 12 weeks – 10 >26 weeks - 16	71	47.8 (SD 11.8)	< 6 weeks – 28 6 weeks – 22 12 weeks – 11 >26 weeks - 10	≥18 years of age, no consultation or treatment for shoulder pain within the past 3 months, pain between the neck and elbow at rest or during the	Acute severe trauma (fractures/ ruptures/ dislocation of the shoulder), previous orthopedic surgery, contraindications to manipulative therapy,

							movement of the upper arm, dysfunction of the cervicothoracic spine and adjacent ribs with accompanying pain or restricted movement	signs of cervical nerve root compression, rheumatic disorders, dementia, severe psychiatric/ emotional/ behavioral disorders, shoulder disorder due to general internal disease
Bialoszewski et al. 2011 ⁷	15	52.6 (range 38-61)	4.8 months	15	50.0 (range 38-60)	4.4 months	Diagnosis of chronic RC injury with no indications for surgical treatment	Co-existing medical conditions, use of anti-inflammatory or analgesic medication
Conroy and Hayes 1998 ¹²	7	55.0 (SD 10.2)	N/S	7	50.7 (SD 16.5)	N/S	Pain around the superolateral shoulder region, one or more of the following findings: pain-limited active ROM deficits in humeral elevation, painful subacromial compression, limited functional movement	Cervical/ wrist/ hand involvement, shoulder instability, primary scapulothoracic dysfunction, stage II and III adhesive capsulitis, 3 rd degree musculotendinous tears, advanced AC joint disease, advanced calcific tendinitis or bursitis, severe degenerative bony or ligamentous changes, neurological involvement, unstable fracture of the humerus/ scapula/ clavicle
Kachingwe et al. 2008 ¹⁶	Mobilization 9 Mobilization with movement 9	43.4 (SD 14.7) 48.9 (SD 13.7)	19.2 (SD 24.6) months 22.6 (SD 17.4) months	Exercise 8 Control 7	47.3 (SD 20.1) 45.6 (SD 13.0)	32.5 (SD 60.2) months 70.0 (SD 92.4) months	Superiolateral shoulder pain and at least 2 of 4 of the following: 1) positive Neer test, 2) positive Hawkins-Kennedy test, 3) painful active shoulder elevation, 4) limitation with functional movement	Adhesive casulitis, grade III RC tear, calcific tendinitis, systemic or neurological disorder, cervical radiculopathy, history of shoulder surgery, corticosteroid injection within the past month, physical therapy treatment within the past

							patterns of hand behind the back or hand behind the head	3 months
Munday et al. 2007 ²²	15	22 (range 16-38)	N/S	15	23 (range 19-23)	N/S	Inability to elevate the arm greater than 100° in the scapular plane without pain at the anterior shoulder, symptoms present >1 month and <1 year	Shoulder pain not of musculoskeletal origins, medical condition that would exclude the patient from receiving physical therapy care, active inflammatory disease, infection, cancer, neuromuscular disorders, fractures around the shoulder, referred pain from the cervical spine
Senbursa et al. 2007 ²⁹	15	48.1 (SD 7.5)	N/S	15	49.5 (SD 7.9)	N/S	Shoulder pain with no major shoulder trauma, pain-limited marked loss of active and passive shoulder ROM	physical therapy treatment within 2 years, history of frozen shoulder, AC joint disorder, GH joint arthritis, calcific tendinitis, shoulder instability, post-traumatic disorders, shoulder surgery, elbow/ hand/ wrist/ cervical spine disorders
Senbursa et al 2011 ³⁰	30	50.5 (SD 10.6)	N/S	25 (supervised exercise) 22 (home exercise)	48.2 (7.9) 48.0 (9.0)	N/S N/S	Partial supraspinatus tear (stage I) and/or SIS diagnosis	Shoulder trauma, instability, frozen shoulder, AC and GH joint problems, calcific tendinitis, shoulder surgery, history of disease in the hand/ wrist/ cervical region, physical therapy or rehabilitation program within the past two years

Winters et al. 1997* ³⁵ - synovial group defined as: patients with pain originating from subacromial structures - shoulder girdle group defined as: patients with pain and limited range of motion not due to synovial structures	Shoulder girdle group 29 Synovial Group 32	Shoulder girdle group 43.9 (SD 12.6) Synovial Group 46.7 (SD 12.1)	Shoulder girdle group 3 weeks Synovial Group 9 weeks	Shoulder girdle group <i>Physiotherapy</i> 29 Synovial Group <i>corticosteroid injection</i> 47 <i>physiotherapy group</i> 35	Shoulder girdle group <i>Physiotherapy</i> 46.4 (SD 11.2) Synovial Group <i>corticosteroid injection</i> 53.5 (SD 12.5) <i>physiotherapy group</i> 53.1 (SD 12.6)	Shoulder girdle group <i>Physiotherapy</i> 4 weeks Synovial Group <i>corticosteroid injection</i> 8 weeks <i>physiotherapy group</i> 8 weeks	Localized pain in the region of the deltoid, AC joint, superior part of the trapezius muscle and scapula	Treatment for shoulder complaints within 6 months, bilateral shoulder complaints, presence of rheumatic disorders, shoulder complaints due to trauma (fracture, dislocation, RC rupture), herniated cervical disc, dementia or other psychiatric disorders
Yiasemides et al 2011 ³⁶	47	62 (range 35-85)	9.7 (SD 12) months; 95%CI [6.3, 13.3]	51	58 (range 27-81)	22 (SD 38) months; 95% CI [12.1, 32.8]	Painful flexion or abduction >1 month, pain or restriction during passive accessory movements at the GH, AC, or SC joint, or pain during passive scapular movements	<18 years of age, unable to understand English, shoulder symptoms reproduced during active cervical spine movements, reproduction of symptoms during palpation of the cervical or thoracic region, paresthesia in affected limb, contraindication to passive shoulder joint mobilization, shoulder flexion or abduction ROM <140°, shoulder

								pain from inflammatory or neoplastic disorder, history of shoulder surgery or trauma within the past 4 weeks, self-report of shoulder instability
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Table 2. Type and location of manual therapy used in each study. Shoulder = shoulder girdle (acromioclavicular, sternoclavicular, and/or glenohumeral joints), Spine = thoracic spine (thoracic spine, cervicothoracic junction, ribs)

Study	Location		Type	
Atkinson et al. 2008 ¹	Shoulder			Manipulation
Bang and Deyle 2000 ²	Shoulder	Spine	Mobilization	Manipulation
Barbosa et al. 2008 ³	Shoulder		Mobilization	
Bennell et al. 2007 ⁴	Shoulder	Spine	Mobilization	
Bergman et al. 2004 ⁵		Spine	Mobilization	Manipulation
Bialoszewski et al. 2011 ⁷	Shoulder		Mobilization	
Conroy and Hayes 1998 ¹²	Shoulder		Mobilization	
Kachingwe et al. 2008 ¹⁶	Shoulder		Mobilization	
Munday et al. 2007 ²²	Shoulder			Manipulation
Senbursa et al. 2007 ²⁹	Shoulder		Mobilization	
Senbursa et al. 2011 ³⁰	Shoulder		Mobilization	
Winters et al. 1997 ³⁵	Shoulder	Spine	Mobilization	Manipulation
Yiasemides et al. 2011 ³⁶	Shoulder		Mobilization	

Table 3. Intervention parameters for studies using mobilization interventions, as described in each study.

Study	Region Treated	Mobilization Parameters	Frequency of Treatment	Additional Interventions
Barbosa et al. 2008 ³	GH, AC, and SC joints	Twice per session: 1 minute for each movement with 2-3 oscillations per second GH – front, back, longitudinal, lateral movements AC – anterior to posterior SC – anterior to posterior, inferior to superior, and superior to inferior	3 times per week for 10 sessions	Therapeutic ultrasound, eccentric exercise
Bennell et al. 2010 ⁴	GH joint, lower cervical spine, upper and mid thoracic spine	GH – in supine; anteroposterior in 45 abduction and inferior glide in 90 abduction; 4 x 30 sec in each position C5-C7 - grade IV, 4 min T1-T8 – grade IV, 4 min	2 times per week for 2 weeks 1 time per week for the next 4 weeks 1 time every 2 weeks for 4 weeks	soft tissue massage, scapular retraining, home exercise program, postural taping
Bialoszewski et al. 2011 ⁷	GH joint	GH – Kaltenborn's roll-glide techniques, Cyriax deep transverse massage, Mulligan's mobilization	N/S	Transcutaneous electrical nerve stimulation (TENS), ultrasound therapy, therapeutic exercise

		with movement, and “typical techniques” of mobilization in the AP direction		
Conroy and Hayes 1998 ¹²	GH joint, subacromial region	Humeral head inferior glide, posterior glide, anterior glide, and long axis traction; grade I-IV, as indicated; each technique 2-4 times for 30 seconds each for a maximum of 15 minutes	3 times per week for 3 weeks	Hot packs, therapeutic exercise, soft tissue mobilization, patient education
Kachingwe et al. 2008 ¹⁶	GH joint	2 manual therapy groups: Grade I-IV anterior/ posterior/ inferior glide or long-axis distraction; Each applied for 3 times for 30 seconds at the rate of 1 oscillation per 1-2 second Mobilization with movement: 3 set of 10 repetitions with sustained posterior glide to the GH joint while the subject actively flexed the shoulder to the pain-free endpoint	1 time per week for 6 weeks	Supervised exercise 1 time per week, ice pack following exercise/ manual therapy; Daily home exercise
Senbursa et al. 2007 ²⁹	GH joint	N/S	3 times per week for 12 weeks	Manual Interventions (deep friction massage, radial nerve stretching, scapular

				mobilization, PNF) Therapeutic exercise
Senbursa et al. 2011 ³⁰	GH joint	N/S	3 times per week for 12 weeks	Manual Interventions (deep friction massage, radial nerve stretching, scapular mobilization, PNF) Therapeutic exercise
Yiasemides et al. 2011 ³⁶	Any of the shoulder region joints (GH, AC, and SC) and scapula	Sustained or oscillatory manner	1-2 treatment sessions per week for 1 month; additional treatment for 4 weeks, up to a maximum of 12 treatment sessions	Scapular mobilization, advice, therapeutic exercise

GH = glenohumeral, AC = acromioclavicular, SC = sternoclavicular, PNF = proprioceptive neuromuscular facilitation
N/S = not stated within the manuscript

Table 4. Intervention parameters for studies using manipulation interventions, as described in each study.

Study	Region Treated	Mobilization Parameters	Frequency of Treatment	Additional Interventions
Atkinson et al. 2008 ¹	GH joint	Anterior to posterior high-velocity, low-amplitude thrust at the glenohumeral joint	6 treatments over a 2 week period	none
Munday et al. 2007 ²²	GH joint, AC joint, ribs, scapula	High-velocity, low-amplitude thrust into the direction of restricted end feel	8 treatments over a 3-week period	none

GH = glenohumeral, AC = acromioclavicular, SC = sternoclavicular

Table 5. Intervention parameters for studies using both mobilization and manipulation interventions, as described in each study.

Study	Region Treated	Mobilization Parameters	Frequency of Treatment	Additional Interventions
Bang and Deyle 2000 ²	GH, shoulder girdle, cervical spine, upper thoracic spine, costotransverse articulations	Grade I-V mobilization	2 times per week for 3 weeks (6 visits) treatment sessions 30 minutes in length	Soft tissue massage, stretching of the pectoralis minor/ infraspinatus/ teres minor/ upper trapezius/ sternocleido-mastoid/ scalene musculature, Standardized flexibility and strengthening program
Bergman et al. 2004 ⁵	Cervical spine, upper thoracic spine, ribs	High-velocity, low amplitude thrust Low-velocity, high-amplitude mobilizations	Maximum of 6 treatment sessions within 12 weeks	Advice, oral analgesics or nonsteroidal anti-inflammatory drugs, up to 3 corticosteroid injections, therapeutic exercise, massage, physical applications
Winters et al. 1997 ³⁵	Cervical spine, upper thoracic spine, upper ribs, AC joint, GH joint	Mobilization and manipulation	Once per week for 6 treatment sessions	N/S

GH = glenohumeral, AC = acromioclavicular, SC = sternoclavicular, N/S = not stated within the manuscript

Table 6. Comparator treatments used in each study.

Study	Comparator Group Treatment
Atkinson et al. 2008 ¹	Sham laser treatments
Bang and Deyle 2000 ²	Clinic based flexibility and strengthening program
Barbosa et al. 2008 ³	Ultrasound and eccentric rotator cuff/biceps exercise
Bennell et al. 2007 ⁴	Sham ultrasound, application of non-therapeutic gel
Bergman et al. 2004 ⁵	“Usual Care”: progression of advice, medication, corticosteroid injections, physical therapy exercise/modalities
Bialoszewski et al. 2011 ⁷	Transcutaneous electrical nerve stimulation (TENS), ultrasound therapy, therapeutic exercise
Conroy and Hayes 1998 ¹²	Clinic based treatment: hot packs, active range of motion, stretching, strengthening, soft tissue mobilization, patient education
Kachingwe et al. 2008 ¹⁶	Exercise: stretching and rehabilitative exercise Control: advice on posture and activity modification
Munday et al. 2007 ²²	Sham ultrasound
Senbursa et al. 2007 ²⁹	Home exercise program: active range of motion, stretching, and strengthening
Senbursa et al. 2011 ³⁰	Group 1: clinic based stretching, strengthening, and range of motion exercises Group 3: home exercise program of strengthening, and range of motion exercises
Winters et al. 1997 ³⁵	Physiotherapy: exercise therapy, massage, physical applications Corticosteroid injection: one to three injections
Yiasemides et al. 2011 ³⁶	Advice and custom tailored exercise program

Table 7. Methodological Quality Score

Study	PEDro Score
Atkinson et al. 2008 ¹	7
Bang and Deyle 2000 ²	8
Barbosa et al. 2008 ³	6
Bennell et al. 2007 ⁴	9
Bergman et al. 2004 ⁵	8
Bialoszewski et al. 2011 ⁷	6
Conroy and Hayes 1998 ¹²	7
Kachingwe et al. 2008 ¹⁶	9
Munday et al. 2007 ²²	8
Senbursa et al. 2007 ²⁹	7
Senbursa et al. 2011 ³⁰	6
Winters et al. 1997 ³⁵	6
Yiasemides et al. 2011 ³⁶	8

Table 8. Patient-rated outcome measures by study

Study	Outcome Measures
Atkinson et al. 2008 ¹	NPRS
Bang and Deyle 2000 ²	Functional assessment questionnaire, cumulative VAS during functional assessment activities/ resisted break tests/ active shoulder abduction, isometric strength for internal rotation/ external rotation/ abduction
Barbosa et al. 2008 ³	DASH and Constant questionnaires
Bennell et al. 2007 ⁴	SPADI, NPRS for average pain during movement, global rating of change
Bergman et al. 2004 ⁵	shoulder pain scale, functional disability questionnaire
Bialoszewski et al. 2011 ⁷	VAS
Conroy and Hayes 1998 ¹²	SPADI, global perceived effect
Kachingwe et al. 2008 ¹⁶	VAS for 24-hour pain, SPADI
Munday et al. 2007 ²²	VAS, Short-Form McGill Pain Questionnaire (SFMPQ)
Senbursa et al. 2007 ²⁹	VAS (night, rest, movement)
Senbursa et al. 2011 ³⁰	VAS (night, rest, movement), Modified American Shoulder and Elbow Surgeons questionnaire (MASES)
Winters et al. 1997 ³⁵	NPRS, perception of being “cured”
Yiasemides et al. 2011 ³⁶	SPADI, self-rated improvement

NPRS = numeric pain rating scale, VAS = visual analog scale for pain, DASH = Disabilities of the Arm, Shoulder and Hand, SPADI = Shoulder Pain and Disability Index

Table 9. Patient-rated pain outcomes for 11 RCTs included. Positive values indicate treatment favored the manual therapy group.

Pain Outcomes							
Study	Location	Type	Time Point	% Mean Difference in Pain Scores Between Groups	Mean Difference with 95% CI on Respective Pain Questionnaire	Effect Size	Study Size
Atkinson, 2004 ¹	Sh	Mp	2 wk	NSS – 6.8%	6.8 [1.7, 15.3] NPRS-101	0.41	n=60/ 2 groups
Bang & Deyle, 2000 ²	Sh/Sp	Mb/Mp	2 mo	23.0%	205 [16, 394] 900mm VAS	0.61	n=52/ 2 groups
Bennell, 2010 ⁴	Sh/Sp	Mb	22 wk	NSS – 9.0%	0.9 [-0.1, 1.9]	0.35	n=120/ 2 groups
Bergman, 2004 ⁵	Sp	Mb/Mp	6 wk	NSS – 3.8%	0.8 [-0.6, 2.3] 21-pt scale	0.18	n=150/ 2 groups
			12 wk	10%	2.0 [0.3, 3.7] 21-pt scale	0.39	
			26 wk	NSS – 3.3%	0.7 [-1.0, 2.5] 21-pt scale	0.13	
			52 wk	NSS – 5.7%	1.2 [-0.5, 3.0] 21-pt scale	0.22	
Bialoszewski, 2011 ⁷	Sh	Mb	N/S	20%	2.0 [0.7, 3.5] 10-pt scale	0.94	n=30/ 2 groups
Conroy & Hayes, 1998 ¹²	Sh	Mb	3 wk	33%	33.4 [3.3, 63.4] 100mm VAS	1.29	n=14/ 2 groups
Kachingwe, 2008 ¹⁶	Sh	Mb	6 wk	NSS – 23.4%	23.4 [-61.2, 108.0] 100mm VAS	0.28	n=33/ 4 groups
Munday, 2007 ²²	Sh	Mp	1 mo	9%	9.1 [-2.74, 20.94] 100mm VAS	0.58	n=30/ 2 groups
			1 mo	18.6%	8.4 [-2.44, 19.24] 45-pt SFMPQ	0.58	
Senbursa, 2007 ²⁹	Sh	Mb	4 wk	10% - at rest	1.0 [-0.46, 2.42]	0.53	n=30/ 2 groups
				10% - night pain	1.0 [-0.53, 2.53] 10cm VAS	0.49	
				6% - pain with motion	0.6 [-0.72, 1.92] 10cm VAS	0.34	
Senbursa, 2011 ³⁰	Sh	Mb	4 wk	NSS	Mean and SD not provided		n=77/ 3 groups
			12 wk	NSS	Mean and SD not provided		
Winters, 1997 ³⁵	Sh/Sp	Mb/Mp	11 wk	NSS – -3.9%*	-1.1 (-3.4, 1.2) 28-pt scale	-0.23	n=114/ 3 group

sh = shoulder, sp = spine, mb = mobilization, mp = manipulation, NSS = not statistically significant, N/S = not stated within the manuscript, VAS = visual analog scale, SFMPQ = Short Form McGill Pain Questionnaire

* synovial group defined as: patients with pain originating from subacromial structures, acromioclavicular joint, or glenohumeral joint

Table 10. Disability/function outcomes for 9 RCTs included. Positive values indicate treatment favored the manual therapy group.

Study	Location	Type	Time Point	% Mean Difference in Scores Between Groups	Mean Difference with 95% CI (questionnaire and scale)	Effect Size	Study Size
Bang & Deyle, 2000 ² Barbosa, 2008 ³	Sh/Sp	Mb/Mp	2 mo	5.1/45 pts - functional questionnaire	5.1 [0.2, 10.0] points (functional questionnaire, 45-points)	0.59	n=52/ 2 groups
	Sh	Mb	3 wk	20.6%	20.6 [6.2, 35.0] points (DASH, 100 points)	1.66	n=14/ 2 groups
				7.0%	7 [-6.3, 20.3] points (Constant Questionnaire, 100 points)	0.61	
Bennell, 2010 ⁴	Sh/Sp	Mb	22 wk	7.1%	7.1 [0.3, 13.9] points (SPADI, 100 points)	0.34	n=120/ 2 groups
				NSS - 7%	7% [-11.5, 25.5] (reporting "much better" on GROC)	0.14	
Bergman, 2004 ⁵	Sp	Mb/Mp	6 wk	NSS - 5.5%	5.5 [-2.9, 13.8] points (SDQ, 100 points)	0.21	n=150 / 2 groups
			12 wk	NSS - 8.5%	8.5 [-2.0, 18.9] points (SDQ, 100 points)	0.26	
			26 wk	12.7%	12.7 [1.3, 24.1] points (SDQ, 100 points)	0.36	
			52 wk	NSS - 6.9%	6.9 [-3.5, 20.7] points (SDQ, 100 points)	0.23	
Kachingwe, 2008 ¹⁶	Sh	Mb	6 wk	NSS - 4.9%	4.9 [-29.1, 38.9] points (SPADI, 100 points)	0.15	n=33/ 4 groups
Senbursa, 2011 ³⁰	Sh	Mb	4 wk	p=0.013 - difference not provided	Mean and SD not provided (MASES, 100 points)		n=77/ 3 groups
			12 wk	NSS – difference not provided	Mean and SD not provided (MASES, 100 points)		
Winters, 1997 ³⁵ Yiasemides, 2011 ³⁶	Sh/Sp	Mb/Mp	11 wk	NSS: -5.0% synovial group*	survival analysis, no CI		n=114/ 3 group
	Sh	Mb	1 mo	NSS - 1.0%	1.0 [-7.0, 9.0] points (SPADI, 100 points)	-0.05	
			3 mo	NSS – 5.0%	-5.0 [-12.0, 3.0] points (SPADI, 100 points)	0.25	n=98/ 2 groups
			6 mo	NSS - 0.0%	0.0 [-7.0, 7.0] points (SPADI, 100 points)	0.02	

Sh = shoulder, Sp = spine, Mb = mobilization, Mp = manipulation, NSS = not statistically significant, DASH = Disabilities of the Arm, Shoulder and Hand, SDQ = Shoulder Disability Questionnaire, SPADI = Shoulder Pain and Disability Index, SD = standard deviation

* synovial group defined as: patients with pain originating from subacromial structures, acromioclavicular joint, or glenohumeral joint

Chapter 3: Thoracic Spine Manipulation in Patients with Subacromial Pain Syndrome Does Not Immediately Alter Thoracic Spine Kinematics, Thoracic Excursion, or Scapular Kinematics

Abstract

Study Design: Randomized Controlled Laboratory Study

Objectives: To determine if thoracic spinal manipulative therapy (SMT) alters thoracic kinematics, thoracic excursion, and scapular kinematics as compared to a sham SMT in patients with subacromial pain syndrome; and secondarily to determine if these mechanistic changes are related to changes in patient-rated outcomes.

Background: Prior studies indicate that thoracic SMT can improve pain and disability in patients with subacromial pain syndrome. However, the mechanisms underlying these benefits are not well understood which limits the directed use of SMT.

Methods: Subjects with shoulder impingement symptoms (n=52) were randomly assigned to receive 1 visit of thoracic SMT or sham SMT, consisting of SMT applied to the lower, middle, and upper (cervicothoracic junction) thoracic spine. A 3-dimensional electromagnetic tracking system was used to measure scapular and thoracic kinematics during active arm elevation, and thoracic excursion at end-range of flexion and extension. Patient-rated outcomes measures were pain (Numeric Pain Rating Scale-NPRS), function (Pennsylvania Shoulder Score-Penn), and global rating of change (GROC).

Results: There were no significant differences between treatment groups for the thoracic kinematics or excursion, shoulder kinematics, or patient-rated outcomes ($p > 0.05$). Regardless

of group, there was a decrease in scapular external rotation over time during ascending arm elevation (mean difference=0.94°, 95% CI [0.33°, 1.56°], p=0.003) and descending elevation (mean difference=0.77°, 95% CI [0.03°, 1.51°], p=0.041), as well as improved NPRS (mean difference=1.2 points, 95% CI [0.3, 1.8], p<0.001) and Penn (mean difference=9.1 points, 95% CI [6.5, 11.7], p<0.001) scores. There were no correlations between changes in thoracic and shoulder mechanistic variables or the changes in mechanistic variables and improvements in NPRS or Penn scores across the study sample.

Conclusion: Thoracic spine extension and excursion did not change following thoracic SMT. There were small, but likely not clinically meaningful changes in shoulder kinematics in both groups. Patient-rated pain and function did improve following treatment in both groups, but there were not any greater benefits seen in the SMT group than the sham group. Furthermore, improvements in patient-rated outcomes were not related to changes in thoracic spine mobility in the SMT. Overall, alterations in thoracic spine mobility do not appear to be responsible for improved outcomes in patients with subacromial pain syndrome. Other measures of thoracic spine motion and neurophysiological mechanisms should be investigated as mechanisms of SMT.

Introduction

Shoulder pain is one of the most common musculoskeletal pain complaints in general medical practice, second to spine pain.¹⁰ The prevalence of shoulder pain is estimated at 16% to 48%,^{10, 32} and the direct cost for treatment in the United States in the year 2000 was reported at \$7 billion.¹⁹ Studies report improved patient-rated outcomes of shoulder pain and function,^{3, 8, 22, 37, 41} and shoulder range of motion³⁷ after rehabilitation programs that included thoracic spinal manipulative therapy (SMT) as a single intervention or combined with exercise. However, the mechanisms by which thoracic SMT improves pain and shoulder motion have not been established. Characterizing the mechanisms that underlie the benefits of thoracic SMT is imperative, to aid the directed use of SMT as a treatment for patients with shoulder pain.

Manual therapy has been used as a treatment intervention in healthcare and the healing arts for hundreds of years.^{14, 31} Manual therapy is the use of hands-on techniques to treat soft tissue and joint structures to modulate pain, improve joint range of motion, facilitate movement, and improve function.^{14, 18, 31} Clinical utilization of SMT is typically based on a biomechanical model, with techniques aimed at improving faulty spinal joint motion.^{14, 18} A cluster of clinical exam and medical history findings identified as predictors of a favorable response to thoracic SMT for patients with shoulder pain have also been theorized to direct the use of SMT.²² However, these predictive characteristics have not been validated, and it is possible that these findings could also identify individuals with favorable natural history rather than those who are likely to respond to thoracic SMT. This further highlights the need for understanding the mechanisms behind improved patient-rated outcomes following thoracic SMT.

Shoulder pain associated with subacromial impingement syndrome is often treated with manual therapy. The clinical diagnosis of subacromial impingement syndrome can include

several pathologies affecting the biceps tendon, the rotator cuff tendons, labrum, coracoacromial ligament, and subacromial bursa.^{9, 27, 30} ‘Impingement’ indicates an exclusive compression mechanism. However, intrinsic mechanisms may also lead to pathologic changes in subacromial structures.³⁵ Subacromial pain syndrome may be a more appropriate descriptor of shoulder pain at the subacromial region.

Reduced thoracic mobility has been linked to shoulder pain,^{28, 29, 36, 39} reduced shoulder elevation¹² and altered scapular kinematics.¹⁶ Specifically, decreased thoracic flexion/extension excursion^{34, 39} and altered segmental mobility of the thoracic spine have been noted in patients with subacromial pain syndrome.^{28, 29, 36} Theoretically, treatments to correct thoracic spine mobility losses are used to improve shoulder motion and pain. Manual therapy interventions directed at the thoracic spine as a stand-alone treatment or combined with exercise has been shown to improve shoulder pain.^{1, 3, 8, 22, 26, 37, 41} Specifically, manual therapy to address impairments at the thoracic spine have shown improved clinical outcomes compared to exercise interventions or typical primary care interventions in the treatment of shoulder pain^{1, 3, 41} Single-arm trials of thoracic SMT as a stand-alone treatment,^{8, 22, 37} have reported immediate and short-term improvements in shoulder pain,^{8, 26, 37} shoulder function / disability,^{8, 26} global rating of change,^{22, 37} and shoulder range of motion.³⁷ From these studies,^{8, 22, 26, 37} no cause and effect relationship can be established, as these were single-arm studies without a comparator.

Mechanisms of thoracic SMT in those with subacromial pain syndrome were examined in a prior single-arm study.²⁶ A single session of thoracic SMT did not result in changes in thoracic excursion mobility. A small decrease in scapular upward rotation was noted following SMT, however this was likely not clinically meaningful. This prior trial lacked a control group, so it is unclear if passage of time or natural history explained these findings.

The theoretical framework of this study is that thoracic SMT will lead to changes in thoracic spine mobility, with accompanying changes in shoulder kinematics and patient-rated outcomes of shoulder pain and function (Figure 1). The primary purpose of this study was to characterize the effects of thoracic SMT in patients with subacromial pain syndrome with regard to direct biomechanical changes in thoracic spine motion, as measured by thoracic extension during active arm elevation and total thoracic flexion and extension excursion. The secondary purpose of this study was to examine the effects of thoracic SMT on shoulder kinematics and patient-rated outcomes, and determine if these changes are related to those in thoracic spine mobility. It is hypothesized that patients receiving thoracic SMT compared to sham thoracic SMT will show: 1) increased thoracic spinal extension during arm elevation, 2) increased thoracic spinal excursion (combined total flexion and extension), 3) improved scapular kinematics (increased external rotation and posterior tilt and decreased clavicular protraction and elevation), 4) improved patient-rated pain and function/disability, and 5) improvements in thoracic spinal extension and thoracic excursion will be related to changes in scapular kinematics and patient-rated outcomes of pain and function/disability.

Methods

Participants

Subjects were tested and treated in the COOR research lab in the Physical Therapy Department of Virginia Commonwealth University. The study included 52 participants with subacromial pain syndrome, who were randomly assigned to either a SMT group (n=26) to receive a standardized dose of thoracic SMT or to a sham SMT group to receive a standardized sham treatment (n=26), a look-alike treatment without the thrust during SMT. Participant characteristics are depicted in Table 1.

Subjects with shoulder pain were recruited from local physical therapy clinics, orthopedic physicians' offices, and the community from November 2012 thru April 2013. The inclusion criteria for subjects were: 1) pain \geq 6 weeks, 2) pain \geq 2/10 on an 11-point numeric pain rating scale (NPRS), and 3) be 18 - 60 years old. Subjects also had to have 3 of 5 clinical signs of subacromial pain syndrome: 1) positive Hawkins Test, 2) positive Neer Test, 3) pain during active elevation $> 60^\circ$ in the scapular or sagittal plane, 4) positive Jobe/Empty Can test for pain or weakness, 5) pain or weakness with resisted shoulder external rotation with the arm at the side.²¹ Subjects were excluded if they have 1) a history of shoulder, cervical spine, or thoracic spine surgery, 2) a primary complaint of neck or thoracic pain, 3) signs of central nervous system involvement, 4) signs of cervical nerve root involvement, 5) contraindications to manipulative therapy such as osteoporosis, metastatic disease, systemic arthritis, 6) primary diagnosis of adhesive capsulitis, 7) primary instability of the shoulder, or 8) reproduction of shoulder or arm pain with cervical rotation to the ipsilateral side, axial compression, or Spurling's Test.

Procedures

All subjects were provided verbal and written explanation of study procedures and signed an informed consent approved by Virginia Commonwealth University prior to participation. Subjects completed an intake questionnaire consisting of health screening questions, demographics, and symptom history. They also completed a baseline numeric pain rating scale (NPRS) and Pennsylvania Shoulder Score (Penn).¹⁷ The NPRS is an 11-point scale ranging from 0-10, with 0 representing "no pain at all" and 10 representing "pain as bad as it can be," and it has shown good reliability and responsiveness in patients with shoulder pain.²³ The Penn is a shoulder specific self-report questionnaire that has been found to be reliable and valid for use in

patients with shoulder disorders.¹⁷ Scores on the Penn range from 0-100, with lower scores indicative of lower levels of function and greater disability.

Next, participants completed baseline shoulder and thoracic kinematics testing. After baseline testing, participants were randomly assigned to receive SMT or sham SMT treatment. Both the SMT and sham SMT treatments were administered by a licensed physical therapist (treating investigator) with 11 years of orthopedic physical therapy experience. The SMT interventions were applied to the lower thoracic spine, middle thoracic spine, and cervicothoracic junction. Following the treatment, kinematic measures and the NPRS were administered again. Participants were also asked to complete a follow-up NPRS and Penn, as well as a global rating of change questionnaire¹⁵ (GROC) 24-48 hours following treatment. A flow chart of experimental procedures is shown in Figure 2.

Randomization and Blinding

Random allocation of participants to treatment groups was achieved via a computer generated list using random blocking (nQuery Advisor, Statistical Solutions, Saugus, MA). A lab assistant placed the treatment assignments into sequentially numbered privacy envelopes in order to conceal treatment group allocation. Participants were informed that the purpose of the study was to examine the effects of manual therapy directed at the thoracic spine, and they could receive an active treatment or look-alike, placebo treatment.

Thoracic Manipulation and Sham Manipulation

The SMT interventions were applied to the lower, middle, and upper (cervicothoracic junction) thoracic spine. Each regional technique was applied 2 times, for a total of 6 thoracic SMT or sham-SMT applications. These techniques have previously been used in clinical trials investigating the effects and outcomes of thoracic SMT in patients with shoulder pain.^{8, 22, 37} For

all thoracic SMT, a high-velocity, low-amplitude thrust was applied at the end of the available spinal motion as the patient exhaled. During the middle and lower thoracic SMT, the participants were prone, and the thrust was directed in the posterior to anterior direction (Figure 3). During the cervicothoracic junction manipulation, the participants were seated, and the thrust was provided as an axial (cephalad) distraction (Figure 2). The sham-SMT was performed with identical body positioning of both the patient and therapist. The therapist followed the patient through the same range of motion, but no manipulative thrust was delivered at the end of the exhalation. This sham-SMT was validated previously as plausible and believable as an active treatment.²⁰

Thoracic and Shoulder Kinematics

The three dimensional kinematics of the scapula and humerus were measured with a 6 degree of freedom electromagnetic tracking apparatus (Polhemus 3Space Fastrak electromagnetic-based motion capture system (Polhemus, Colchester, VT)) integrated with Motion Monitor software (Innovative Sports Technologies Inc., Chicago IL). Kinematic data was sampled at 30 Hz. The transmitter was adjusted to be level with the top of the participant's sternum when in the seated test position. Sensors were placed in accordance with the International Society of Biomechanics (ISB) protocol.^{42, 43} Three electromagnetic sensors were secured to the subject using double sided tape and reinforced with cover tape over the top of the sensor. Sensor placement is depicted in Figure 4. The thoracic sensor was placed on the sternum, just below the jugular notch, the scapular sensor on the flat posterior-lateral acromion, and the humeral sensor on the distal posterior arm. A fourth sensor was used to digitize location of the bony landmarks as per the ISB protocol for measuring scapular and glenohumeral kinematics.⁴³ The following points were palpated and digitized: thorax = T1, T7, and

suprasternal notch; scapula = acromial angle, inferior angle, root of the scapular spine, and acromioclavicular joint; humerus = medial epicondyle and lateral epicondyle. The location of the center of the humeral head was defined as the point of least movement between the scapula and the humerus, calculated by a least squares algorithm as the humerus was moved through short arcs of motion.^{40, 42} The digitized landmarks, segmental axis systems, and Euler angle rotational sequences for the thoracic spine and scapula are detailed in Appendix 1. Thoracic extension was measured with respect to rotation around the axis coincident with the Z-axis of the global coordinate system (Figure 5). The scapular kinematic variables of interest were scapular external rotation, upward rotation, and posterior tilting, as well as clavicular elevation and clavicular protraction to define scapular positions (Figure 5). Scapular rotations were measured directly by the scapular sensor, and clavicular motions were calculated based on the location of the suprasternal notch (tracked with the thoracic sensor) and the acromion-clavicular joint (tracked by the scapular sensor).

The participants were tested in the seated position in front of the electromagnetic tracking transmitter. Participants sat in a backless chair that had a side post rising from each side in order to allow for securing the participant to the chair using belts around the hip and lumbar regions (Figure 4). Once seated in the chair with their feet flat on the floor, a belt was placed as low around the participant's hips as possible, while another belt was placed around the lumbar region, with the top of the belt at lumbar vertebrae 1. The belts were made snug in order to limit lumbar motion during arm elevation for kinematics testing. An investigator blinded to treatment assignment (non-treating investigator) gave subjects instructions during kinematics testing and then left the room during treatment in order to maintain blinding.

Participants held a 1.36 kg (3 lbs) or 2.27 kg (5 lbs) weight in their hands, depending on their body weight (<150 lbs. body weight = 1.36 kg, ≥ 150 lbs. body weight = 2.27 kg). The participant elevated their arms in the scapular plane over their head and returning them to their side 5 times (during a verbal count of 3 seconds up and 3 seconds down). A tester counted aloud to 3 to pace the ascending and descending phase of the arm elevation. The arm elevation task was performed in the scapular plane (scaption), in the thumb-up position using a guide pole as a visual cue to maintain the plane of motion. Scapular rotations and positions were calculated at the arm elevation angles of rest, 30° , 60° , 90° , and 120° using MATLAB software (The MathWorks, Inc; Natick, MA). A measure of thoracic extension was also calculated at the same arm elevation angles based on the motion of the thorax (the digitized position of the suprasternal notch) with relation to the global coordinate system. Scapular and thoracic kinematic data from the middle 3 repetitions of arm elevation were averaged and used for data analysis. Reliability of this measure was determined from a pilot test in 10 healthy individuals. The intraclass correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC) were calculated. Reliability ranged from good to excellent with respect to ICC values.^{13, 33} Thoracic extension had $ICC_{(3,1)}$ of 0.78-0.91, SEM of 1.01 - 1.50° , and MDC of 1.43 - 2.12° over the arm elevation positions. Scapular rotations of external rotation, posterior tilt, clavicular elevation, and clavicular protraction had $ICC_{(3,1)}$ of 0.79-0.99, SEM of 1.22 - 2.89° , and MDC of 1.80 - 3.6° . Scapular upward rotation also had good to excellent reliability, with $ICC_{(3,1)}$ of 0.72-0.96, but slightly higher SEM and MDC across arm angles, ranging from 2.03 - 5.44° and 4.7 - 12.62° , respectively.

Thoracic Excursion

Total excursion of the thoracic spine from full flexion to full extension was measured with the 6 degree of freedom electromagnetic-based motion capture system. The subject sat in a wooden chair with their feet flat on the floor, and a lap belt was used around the subjects' hips to maintain their position during testing. First, thoracic flexion was measured by asking the participant to allow their arms to hang outside of their legs and bend their spine as much as possible in an effort to move their shoulders toward their thighs, but to not bend forward at the hips. Once in full thoracic flexion, the examiner used a stylus to digitize the location of the spinous process of each of the 12 thoracic vertebra (T1- T12) (Figure 6). To measure extension, the participant was asked to start in an upright, seated position, with their arms down to their side, hands resting comfortably on top of their proximal thighs, arch their back as far as they could and look up toward the ceiling. Once maximum extension was achieved, each of the thoracic vertebrae was digitized. The digitized thoracic spinous processes of T1-T12 were plotted graphically using MATLAB software. The angle between the upper third and lower third of the thoracic spine was measured as the thoracic spine angle. The software constructed best-fit lines through the digitized locations of T1-T4, as well as T9-T12. The sagittal plane angle between those lines was calculated using the equation:

$$\phi = \tan^{-1} \left(\frac{m2 - m1}{1 + (m1 \bullet m2)} \right)$$

where ϕ is the thoracic spinal angle, $m1$ is the slope of the line through T1-4, and $M2$ is the slope of the line through T9-12. The difference between maximal flexion and maximal extension thoracic spine angles was recorded as thoracic spinal excursion. This calculation for thoracic spine motion is similar to the calculation used by Crawford et al. to measure static kyphosis and thoracic extension excursion using inclinometers at the upper and lower thoracic spinal

segments.¹² The reliability for thoracic excursion was excellent, with $ICC_{(3,1)}=0.96$, $SEM=3.34^\circ$, and $MDC=4.73^\circ$.

Shoulder Flexion Range of Motion

Shoulder flexion was measured in two ways, to the point of initial pain and maximal available shoulder flexion. Participants were asked to sit in a chair with a fixed back, and keep their back firmly against the back during testing. A digital inclinometer was placed along the long axis of the humerus to measure flexion range of motion. Each measurement was taken twice and averaged. To measure shoulder flexion at the initial onset of pain, participants were asked to raise their arm to the point where initially felt shoulder pain. To measure maximal shoulder flexion, participants were asked to raise their arm as far as they could. Flexion range of motion had an $ICC_{(3,1)}=0.94$, $SEM=0.92^\circ$, and $MDC=1.30^\circ$.

Sample Size Calculation

Sample size calculations were performed using nQuery Advisor software (Statistical Solutions, Saugus, MA). Sample size calculations were based on a mixed model ANOVA comparing the changes between the SMT and sham SMT groups with 80% power and a significance level of $\alpha=0.05$. Kinematics data was collected in a pilot study of 6 individuals with subacromial pain syndrome who received either SMT ($n=3$) or sham SMT ($n=3$) treatment. The kinematic variable with the highest sample estimate was used to determine sample size. The variable of scapular posterior tilt required the largest sample size. The effect size for this variable was 0.79, requiring a sample of 26 subjects per group.

Data Analysis

All statistical analyses were performed using JMP Pro 10.0.0 software (SAS Institute, Cary NC) with level of significance set at $\alpha=0.05$. Scapular kinematics and thoracic extension

recorded during the arm elevation task were compared using separate mixed-model analysis of variance (ANOVA). The model was fit using the 3 factors of treatment group (SMT or sham-SMT), time (pre-treatment and post-treatment), and arm angle (30°, 60°, 90°, and 120°), resulting in a 2 x 2 x 4 mixed-model ANOVA. The ascending and descending phases of the arm elevation task were analyzed separately. Pair-wise comparisons using a Bonferroni corrected α were made based on any significant interactions of group and time or main effects. The change in thoracic excursion between the treatment groups was compared using a 2 x 2 mixed model ANOVA. NPRS scores were compared using a 2 x 3 mixed-model ANOVA using the factors of treatment group and time (pre-treatment, post-treatment, and 24-48 hour follow-up). Penn scores were compared using a 2 x 2 ANOVA using the factors of treatment group and time (pre-treatment and 24-48 hour follow-up). A t-test was used to compare GROC scores between the groups at the 24-48 hour follow-up. Shoulder flexion measures were compared using a 2 x 2 mixed model ANOVA using the factors of Group and Time (pre-post-treatment). Correlations between changes in thoracic extension and changes in each of the scapular kinematics variables were calculated, as well as correlations between changes in thoracic excursion and changes in the scapular kinematics variables. Correlations between baseline pain and Penn scores, as well as changes in pain and Penn scores were examined with relation to the changes in each of the thoracic and scapular kinematics variables and thoracic excursion. The correlations were performed separately for the entire study sample and the thoracic SMT group alone. An $\alpha=0.0125$ was used for the kinematics correlations, as 4 correlations were performed for each of the 4 arm angles in the ascending phase and the descending phase of arm elevation. The credibility of the sham thoracic SMT was assessed using a two-sample test of proportions to

compare the proportion of participants in each treatment group who felt that they received an active form of treatment.

Results

Patients with subacromial pain syndrome were recruited for this study (n=52), with even allocation of subjects between the two treatment groups (n=26). There were no differences in baseline variables between the groups (Tables 1). Tables 2-7 show the pre-treatment and post-treatment values for the scapular kinematics and thoracic extension at each arm angle, as well as the pre-treatment and post-treatment values for thoracic excursion. The patient-rated outcomes for the NPRS and Penn Shoulder Score are included in Table 8. Figures 7-16 give graphical representations of the kinematics and patient rated variables.

The mixed-model ANOVA results for the thoracic extension and scapular kinematics variables during the arm elevation task are available in Table 9. There were no 3-way Group x Time x Arm Angle interactions for thoracic extension or any of the 5 scapular kinematic variables during the arm elevation task ($p \geq 0.895$). There were no 2-way Group x Time interactions for any of the scapular kinematics variables or thoracic extension during the arm elevation task ($p \geq 0.532$). During the ascending phase of arm elevation, there was a Group x Arm Angle interaction for both UR and PT, but pair-wise comparisons between the groups per arm angle (30°, 60°, 90°, 120°) using a Bonferroni corrected $\alpha=0.013$ failed to show a significant difference between the groups at any arm angle ($p \geq 0.116$). There was a Group x Arm Angle interaction for scapular UR during the descending phase, but pair-wise comparisons between the groups at each arm angle using a Bonferroni corrected $\alpha=0.013$ failed to show a significant difference between the groups ($p \geq 0.063$). There was a main effect for Time for scapular ER during the ascending phase of the arm elevation task ($p=0.003$), with an overall decrease in

scapular ER of 0.9° [95% CI 0.3° , 1.6°] from pre-treatment to post-treatment across both groups (SMT group = 0.9° , 95% CI [0.0, 1.7], sham group = 1.0° , 95% CI [0.2, 1.9]). There was also a main effect for Time for scapular ER during arm descending phase ($p=0.041$), with an overall decrease in scapular ER of 0.8° , 95% CI [0.0° , 1.5°] from pre-treatment to post-treatment across both groups (SMT group = 0.8° , 95% CI [-0.2° , 1.9°], sham group = 0.7° , 95% CI [-0.3° , 1.7°]). For thoracic excursion measures, there was no Group x Time interaction ($p = 0.779$), nor a main effect for Time ($p = 0.374$). There was a main effect for Group ($p = 0.032$), with those in the SMT group having greater excursion values vs. sham SMT, regardless of Time. There were no Group x Time interactions for patient-rated outcomes of pain (NPRS) or function (Penn), with $p = 0.735$ and $p = 0.886$, respectively. There was a main effect for Time for the NPRS ($p < 0.001$) and the Penn ($p < 0.001$), indicating both groups had significant decreases over time for the NPRS and Penn scores. Specifically, the NPRS decreased across the groups 1.0 , 95% CI [0.4 , 1.6] points from pre-treatment to post-treatment and 1.2 , 95% CI [0.3 , 1.8] points from pre-treatment to the 24-48 hour follow-up. The Penn scores improved across the groups by 9.1 points, 95% CI [6.5 , 11.7] from pre-treatment to 24-48 hour follow-up. A t-test revealed no statistically significant difference in the GROC between the two treatment groups, ($t_{(49)}=0.57$, $p=0.574$). Table 10 shows the results of the statistical analysis for thoracic excursion, NPRS, and Penn.

There were no differences between the groups for change pre- to post-treatment (Group x Time) in either of the shoulder flexion measurements ($p \geq 0.52$). There was a significant effect over time for pain-free shoulder motion ($p < 0.001$), with a mean increase of 21.4° , 95% CI [15.0° , 27.9°] across both groups from pre- to post-treatment (thoracic SMT = 20.6° , 95% CI

[11.6°, 29.8°], sham SMT = 22.1°, 95% CI [13.1°, 31.2°]). There was no change over time for maximum shoulder flexion ($p=0.146$).

During the ascending phase of arm elevation, the only correlation between thoracic extension and scapular kinematics that reached statistical significance for the study sample was with external rotation at 30° ($p=0.004$) and 60° ($p=0.010$), with correlation coefficients of $r = 0.38$ and $r = 0.34$, respectively. That would indicate a fair relationship, in which the amount of scapular external rotation that can be accounted for through thoracic extension (r^2) is 12-14% at these arm angles. During the descending phase of arm elevation, the only correlations to have a significant relationship with thoracic extension within the study sample were external rotation at 120° ($r = -0.35$, $p = 0.008$), posterior tilt at 30° ($r = -0.36$, $p=0.006$), and clavicular elevation at 120° ($r = 0.39$, $p=0.003$). These would again represent fair relationships, in which 12-15% of the variability in these specified scapular rotations at these arm angles could be accounted for through thoracic extension. Overall, external rotation was found to significantly correlate with thoracic extension at 3 of 8 arm angles examined, while posterior tilt and clavicular elevation were only found to have a significant relationship with thoracic extension at 1 out of 8 arm angles. Due to the number of relationships examined and the sporadic distribution of significant findings, these relationships may be due to chance. Across the study sample thoracic excursion did not demonstrate any statistically significant relationships with the scapular kinematics variables. When the thoracic SMT group was examined separately, the only relationships that reached statistical significance were thoracic extension and scapular ER at 30° ($r=0.50$, $p=0.006$) and thoracic extension and clavicular elevation at 90° ($r=0.57$, $p=0.002$), with no significant relationships noted between thoracic excursion and any scapular kinematic variables. Having only two significant findings over the high volume of comparisons, which did not correspond

with any of the significant relationships found with the entire study sample suggests that these may be chance findings.

None of the correlations for the entire study population or the SMT group reached a level of statistical significance for pain or baseline pain with any of the kinematics variables or thoracic excursion ($p \geq 0.070$). The only significant correlation between baseline Penn score and scapular external rotation was at 30 degrees ($p=0.001$) in the descending phase, with a coefficient of 0.43. On face value, this would mean that there is a moderate positive relationship between changes in scapular external rotation at this arm angle and change in Penn score, but since this was the only significant relationship noted, it is difficult to say that it did not occur by chance due to the large number of comparisons that were made.

The majority of participants reported that they believed they received an active treatment; 77% in the thoracic SMT group and 71% in the sham SMT group. The two-sample test of proportions was not significant ($p = 0.380$), indicating that there was no difference between the proportion of participants between groups who reported they received an active form of treatment.

Discussion

Mechanistically, this study showed that thoracic SMT did not lead to direct changes in thoracic spine mobility, specifically in thoracic extension during arm elevation (kinematics) or thoracic excursion. This indicates that thoracic SMT did not have an immediate biomechanical effect directly at the site of SMT application in patients with subacromial pain syndrome. Additionally, thoracic SMT did not cause changes at the affected shoulder with respect to scapular kinematics or patient-rated outcomes of pain and function as compared to sham SMT. There were improvements in patient-rated outcomes in both groups across time. However, there

was no greater benefit in outcomes in the thoracic SMT group over the sham-SMT group. We did not find any meaningful correlations between changes in thoracic mobility and scapular kinematics or and meaningful correlations between changes in thoracic mobility or shoulder kinematics and patient-rated outcomes. The exact mechanism(s) of thoracic SMT in patients with subacromial pain syndrome is unclear, and immediate benefits appear to be no better than a sham SMT.

Since no changes in thoracic spine mobility during arm elevation or in thoracic spinal excursion were found with thoracic SMT, this limits the rationale for the use of thoracic SMT based solely on biomechanical changes at the thoracic spine in patients with shoulder pain. Our findings are consistent with those of previous studies that failed to find changes in thoracic kinematics or segmental mobility (stiffness) following thoracic SMT.^{11, 26} Muth et al. examined effects of a single treatment session of mid and upper thoracic SMT, and reported no changes in gross thoracic excursion after thoracic SMT in patients with subacromial pain syndrome.²⁶ Furthermore, Campbell et al. reported no significant changes in thoracic segmental mobility following thoracic SMT in asymptomatic participants.¹¹ Our findings combined with these prior studies suggest that thoracic SMT has no effect on measureable thoracic spine mobility.

Scapular external rotation during arm elevation decreased in both treatment groups, but there was no difference between groups. The decrease in scapular external rotation was less than 1°, which is less than the measurement error and therefore may not be clinically meaningful. No other significant changes in any of the scapular kinematic variables were found between groups or over the course of treatment. Our results are largely consistent with the results of the prior study of thoracic SMT delivered to patients with subacromial pain syndrome by Muth et al.,²⁶

which reported a small, potentially non-clinically meaningful decrease in scapular upward rotation (the amount of change was not reported) and no changes in other scapular kinematics.

Patient-rated outcomes were improved over time in both treatment groups, but no differences were noted between groups. Only patient-rated pain (NPRS) over the course of 24-48 hours after treatment met the threshold of clinically meaningful change.²⁴ We saw a decrease in pain across both groups of 1.0, 95% CI [0.4, 1.6] point from pre-treatment to post-treatment measures and 1.2, 95% CI [0.3, 1.8] points from pre-treatment to the 24-48 hour follow-up. A change of 1.1 point on the NPRS represented a clinically meaningful change in patients with shoulder pain.²⁴ Only 8 (31%) patients in the thoracic SMT and 11 (42%) patients in the sham SMT group exceeded the clinically meaningful pain reduction of 1.1 on the NPRS. Although statistically significant, the improvements in Penn score were less than the minimal clinically important difference (MCID) of 11.4 point (minimal detectable change of 12.1-points) to deem a clinically meaningful benefit,¹⁷ and a mean change in the GROC score of +1 to +2 indicates a small and non-meaningful improvement.¹⁵ Only 6 (23%) patients in the thoracic SMT group and 11 (42%) patients in the sham SMT group exceeded the MCID of 12 points for the Penn.

The magnitude of change in pain that we found was similar to those from 2 prior single-arm clinical trials of a single session of thoracic SMT^{8, 26} in patients with subacromial pain syndrome. After thoracic SMT, the 48-hour decrease in pain with impingement tests (Hawkins and Neer's) was 1.1-1.2 points as reported by Boyles et al.⁸, and a 1.1-2.8 point decrease in pain with arm elevation and provocative tests in the study by Muth et al.²⁶ Muth et al.²⁶ also reported that 24 of 30 subjects reported a change in pain that exceeded 2 points with provocative tests, which is a significantly higher proportion than in our study (8 of 26). Because we noted similar

changes in the sham-SMT group suggests that the manipulative thrust may not be component that led to the decrease in pain.

The changes in function indicated by the improvements in Penn scores and GROC were similar to those reported in previous studies.^{8, 26} Both groups showed an increase in Penn scores from pre-treatment to 24-48 hour follow-up of 9.1, 95% CI [6.5, 11.7] points, which is slightly larger than the difference reported by Muth et al. of 7.6, 95% CI [4.1, 11.1]. Although the changes noted in our study and the Muth et al. study were statistically significant, these changes did not reach the MCID of 11.4 points for the Penn.¹⁷ Muth et al.²⁶ also reported that 33% (10 of 30) subjects had an improvement in Penn of ≥ 12 points, which was the same percentage as our study. Boyles et al. also reported significant decrease in Shoulder Pain and Disability Index (SPADI) scores that did not meet the threshold for clinically meaningful difference.⁸ Our mean GROC score (mean across groups = 1.5) was similar to the 1.4 mean score reported by Boyles et al. at their 48-hour follow-up,⁸ however, GROC scores of 1 to 2 represent small and likely non-meaningful change.¹⁵ The GROC of 4.2 reported by Strunce et al.,³⁷ after thoracic SMT did represent a meaningful moderate change.¹⁵ The findings of our study and these previous studies suggest a positive effect with a single dose of manual therapy, but fall mostly short of clinically meaningful differences.

Improvement in pain-free shoulder flexion was significant across both groups, but there was no difference between the groups. The 21.4°, 95% CI [15.0, 27.9] improvement represents a clinically significant change,²⁵ and is similar to that reported by Strunce et al. (38.4°).³⁷ Without significant difference in pain, function, or pain-free shoulder flexion between the thoracic SMT and the sham-SMT groups in our study, it again brings into question whether the manipulative thrust at the thoracic spine is the component of this treatment that brings positive

effects. We are not able to rule out positive effects from factors such as repeated shoulder motion during testing, interaction with a healthcare professional, passage of time, placebo effects, or the positive contributions that could be associated with manual contact (touch). Without a control groups that received no treatment, we also cannot rule out the affects of natural course of disease.

We found improved outcomes in pain and function, consistent with what has been reported in previous studies^{8, 26, 37} using similar SMT dosage and assessment periods at immediate or short-term follow-up. Of these previous studies, only Strunce et al. found improved GROC that was clinically meaningful,³⁷ which may be attributed to the pragmatic approach to treatment based on findings from the manual therapy focused examination. Our study and those by Muth et al. and Boyles et al. used a standardized manual therapy intervention for all participants.^{8, 26} Therefore, it is possible that the impairment based approach used by Strunce et al. may have treated areas of dysfunction for each patient that is not accomplished using a standardized set of manipulative techniques.³⁷ There have also been clinical exam and medical history findings identified by Mintken et al. that may identify individuals with shoulder pain who are most likely to respond favorably to thoracic spinal manipulation.²² These findings have yet to be validated. However, if clinical and history findings do predict patients with shoulder pain likely to benefit from thoracic SMT, any study with a heterogeneous mix of patients may see less positive change across the sample than if patients had been selected based on the increased likelihood of positive outcomes. The major difference between our study and the prior single-arm studies is our use of a comparator treatment group. This is a strength of our study, as it controls for time, interpersonal interaction, and manual contact from a healthcare provider. Both our sham SMT and thoracic SMT group showed similar positive effects in pain

and function following one treatment session that were noted in two of the three single-arm trials, as described above. The fact that similar positive outcomes were noted in both groups, and the only difference in treatment was the manipulative thrust, may indicate that the manipulative thrust may not be the component of SMT that leads to the positive outcome, and other factors associated with the passage of time, manual contact, interaction with a healthcare provider, or placebo effects could be factors relating to improvement.^{2, 7}

Several clinical trials that had thoracic SMT as a part of a manual therapy treatment regimen reported improved patient-rated outcomes over comparator treatments that did not include manual therapy.^{1, 3, 41} These trials also used adjunct treatments and multiple doses of manual therapy over the course of multiple weeks,^{1, 3, 41} and improvements were seen at longer follow-up intervals (2-6 months). Therefore, it is possible that a greater dose of manual therapy or adjunct interventions may help to produce functional improvements with treatments utilizing thoracic SMT. It is difficult to assess the individual contribution of thoracic SMT to the overall outcomes with these prior studies.

Further analysis was done to assess the potential effects of baseline factors of age, BMI, baseline pain, baseline Penn score, duration of symptoms, and gender by adding them individually into the mixed model ANOVA and additionally as covariates in an analysis of covariance (ANCOVA). No statistically significant differences were noted when these variables were used in mixed model ANOVA or ANCOVA. However, a few potential differences in response to thoracic SMT were noted. BMI and duration of symptoms may have an influence on pain and Penn scores in patients who received thoracic SMT. Patients with lower BMI (< 30) or symptoms for ≤ 12 weeks had greater improvements in pain and Penn scores following thoracic SMT. Patients with BMI <30, showed a of 1.4-point (± 2.0) decrease in pain and a 10.6-point

(± 10.2) improvement in Penn score 24-48 hours following treatment, whereas those with BMI ≥ 30 showed a decrease of only 0.4 point (± 2.0) in pain and an improvement of 2.2 point (± 19.9) in Penn score. There was a 1.7-point (± 5.6) reduction in pain and a 14.7-point (± 27.0) improvement in Penn scores among those subjects with more acute symptoms, compared to 0.7-point (± 2.0) reduction in pain and an 8.2-point (± 9.7) improvement in those with more chronic symptoms. However, there were only 6 patients with a BMI ≥ 30 and 3 patients with symptom duration of ≤ 12 weeks, thereby limiting these secondary results. Greater improvements in those patients with less than chronic duration of symptoms is consistent with a previous report that symptoms < 3 months may be one prognostic variable for positive outcome from thoracic manipulation to treat shoulder pain.²² Although there was no statistically significant relationship between groups based on treatment and gender, it is worth noting that men appeared to have greater immediate pain reduction following thoracic SMT than women (men decreased in pain by 1.5 ± 2.5 points, whereas women decreased 0.4 ± 2.5 points immediately post-treatment), so gender specific responses to SMT could be something to consider in future studies. GROC values fell within the range indicative of minimal change for all of the subgroup analyses, so there were no notable finds with regard to this outcome.

To determine if those who had clinically meaningful change in pain may have experienced changes in thoracic mobility or scapular kinematics, mixed model ANOVA were also performed that included only those patients in each group who experienced at least a 2 point change in pain with treatment. Nineteen participants were used for this analysis; $n=8$ from the thoracic SMT group and $n=11$ from the sham SMT group. No meaningful changes were noted pre- to post-treatment in any of the kinematics variables for this subgroup of participants.

This study raises further questions about the mechanisms of manual therapy. Previous authors have indicated that the mechanisms of manual therapy may involve neurophysiological mechanisms related to pain modulation.^{6, 26, 38} Recently, Bialosky et al.⁴ suggested that placebo effect may also be part of the mechanism of manual therapy, and that the failure of a manual therapy intervention to perform better than placebo does not necessarily indicate a failed intervention if both outperform natural history.⁴ Our study did not have a non-treatment group to compare effects to natural history. However, given the short follow-up period, it is not likely that natural history was solely responsible for our observed positive changes.

Limitations

This study used a standardized regimen of thoracic SMT and may not have addressed specific spinal mobility dysfunctions of the individual patients. We also used only a single session of manual therapy, which may not have provided enough of a dosage of thoracic SMT to result in measurable biomechanical changes or larger changes in outcomes. Because only immediate effects were assessed, it is possible that participants were not yet able to realize the full impact of functional improvements over this short follow-up period. There were also no adjunct treatments, such as therapeutic exercise, that could enhance the effects of thoracic SMT. It is also possible that there is a subset of patients with shoulder pain who respond more favorably to thoracic SMT as reported by Mintken et al.²² Our protocol did not limit inclusion based on physical exam or medical history findings that may or may not be predictive of positive outcomes from SMT. The design of this study also did not allow for comparisons assessing the potential for placebo effect from manual therapy. Approximately 20% of study participants were actively seeking care from a healthcare provider for their shoulder pain. Therefore, it is possible that most of our participants had symptoms that were subclinical and may not have shown the

degree of thoracic mobility deficits, scapular kinematic deviations, or pain and functional loss levels as patients who were all actively seeking care. It is also difficult to know the extent of thoracic extension or excursion deficits within our participants since they were not compared to a healthy control group prior to the study, and this could have affected the amount of change that would occur following thoracic SMT. Another limitation to this study is that our inclusion criteria specified that patients rate their pain as ≥ 2 on a 10-point pain scale. This would limit the degree of clinical improvement that these patients could show, as the patients who rated their pain as 2/10 would need to experience near resolution of their symptoms to exceed the MCID for shoulder pain (1.1 points) on a NPRS marked in whole numbers (0, 1, 2, 3... 10). Our measures of thoracic extension kinematics and total extension/flexion excursion are only two measures assessing the spinal biomechanics, so measures such as postural changes or other rotational or side bending components of thoracic motion may provide different results when examining the biomechanical effects of thoracic SMT. We also measured excursion based on static measures of flexion and extension, rather than a dynamic measure of excursion.

Conclusion

Thoracic spine mobility in terms of flexion/extension excursion and extension during arm elevation did not change following thoracic SMT in patients with subacromial pain syndrome. Furthermore, there were no changes in shoulder kinematics at the affected shoulder and no differences in patient-rated pain and function in those undergoing SMT versus sham SMT. Improvements in patient-rated outcomes were not related to changes in thoracic spine mobility and scapular kinematics following thoracic SMT. Therefore, changes in thoracic mobility and scapular kinematics do not appear to be responsible for improvements in patient-rated outcomes of pain and function, indicating that the mechanisms of pain modulation from thoracic SMT may

not be biomechanically rooted. This study suggests that thoracic SMT may improve shoulder pain and function within 24-48 hours of treatment, but this improvement was no better than a sham thoracic SMT. Moreover, only a minority of patients in each group had meaningful changes in pain (≥ 2 points decrease) and function (≥ 12 point increase in Penn) over the 23-48 hour follow-up period.

Future Research

A comprehensive model of the effects of SMT interventions includes affects of pain modulation occurring at the peripheral and/or central nervous system.⁵ Future studies should examine neurophysiological effects independently and in combination with biomechanical effects to comprehensively determine the mechanisms of SMT. Furthermore, assessment of other measures of thoracic motion and position during arm motion or functional activities may provide further insight in the mechanics of SMT at the thoracic spine. Future studies should include patients who are actively seeking care, and have a longer follow-up to characterize the effects of thoracic SMT. Finally, the positive effects of thoracic SMT may be mediated by the addition of exercise and therefore should be considered in future clinical trials.

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. Benz LN, Flynn TW. Placebo, nocebo, and expectations: leveraging positive outcomes. *J Orthop Sports Phys Ther.* 2013;43:439-441.
3. 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.
4. Bialosky JE, Bishop MD, George SZ, Robinson ME. Placebo response to manual therapy: something out of nothing? *J Man Manip Ther.* 2011;19:11-19.
5. 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.
6. 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.
7. Bishop MD, Mintken PE, Bialosky JE, Cleland JA. Patient expectations of benefit from interventions for neck pain and resulting influence on outcomes. *J Orthop Sports Phys Ther.* 2013;43:457-465.
8. 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.

9. Braman JP, Zhao KD, Lawrence RL, Harrison AK, Ludewig PM. Shoulder impingement revisited: evolution of diagnostic understanding in orthopedic surgery and physical therapy. *Med Biol Eng Comput.* 2013; DOI 10.1007/s11517-013-1074-1
10. Broadhurst NA, Barton CA, Yelland LN, Martin DK, Beilby JJ. Managing shoulder pain in general practice--the value of academic detailing. *Aust Fam Physician.* 2006;35:751-752.
11. Campbell BD, Snodgrass SJ. The effects of thoracic manipulation on posteroanterior spinal stiffness. *J Orthop Sports Phys Ther.* 2010;40:685-693.
12. Crawford HJ, Jull GA. The influence of thoracic posture and movement on range of arm elevation. *Physiotherapy Theory and Practice.* 1993;9:143-148.
13. Fleiss JL. *The design and analysis of clinical experiments.* New York: Wiley; 1986; 2-30.
14. Greenman PE. *Principles of manual medicine.* 2nd. Baltimore: Williams & Wilkins; 1996;75-91.
15. Jaeschke R, Singer J, Guyatt GH. Measurement of health status. Ascertaining the minimal clinically important difference. *Control Clin Trials.* 1989;10:407-415.
16. 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.
17. 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.
18. Maitland GD. *Maitland's Vertebral Manipulation.* 7th. New York: Elsevier; 2005;1-15.

19. Meislin RJ, Sperling JW, Stitik TP. Persistent shoulder pain: epidemiology, pathophysiology, and diagnosis. *Am J Orthop (Belle Mead NJ)*. 2005;34:5-9.
20. Michener LA, Kardouni JR, Lopes Albers AD, Ely JM. Development of a sham comparator for thoracic spinal manipulative therapy for use with shoulder disorders. *Man Ther*. 2013;18:60-64.
21. Michener LA, Walsworth MK, Doukas WC, Murphy KP. Reliability and diagnostic accuracy of 5 physical examination tests and combination of tests for subacromial impingement. *Arch Phys Med Rehabil*. 2009;90:1898-1903.
22. Mintken PE, Cleland JA, Carpenter KJ, Bieniek ML, Keirns M, Whitman JM. Some factors predict successful short-term outcomes in individuals with shoulder pain receiving cervicothoracic manipulation: a single-arm trial. *Phys Ther*. 2010;90:26-42.
23. Mintken PE, Cleland JA, Whitman JM, George SZ. Psychometric properties of the Fear-Avoidance Beliefs Questionnaire and Tampa Scale of Kinesiophobia in patients with shoulder pain. *Arch Phys Med Rehabil*. 2010;91:1128-1136.
24. 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.
25. Muir SW, Corea CL, Beaupre L. Evaluating change in clinical status: reliability and measures of agreement for the assessment of glenohumeral range of motion. *N Am J Sports Phys Ther*. 2010;5:98-110.
26. Muth S, Barbe MF, Lauer R, McClure PW. The effects of thoracic spine manipulation in subjects with signs of rotator cuff tendinopathy. *J Orthop Sports Phys Ther*. 2012;42:1005-1016.

27. Neer CS, 2nd. Impingement lesions. *Clin Orthop Relat Res*. 1983;173:70-77.
28. Norlander S, Aste-Norlander U, Nordgren B, Sahlstedt B. Mobility in the cervico-thoracic motion segment: an indicative factor of musculo-skeletal neck-shoulder pain. *Scand J Rehabil Med*. 1996;28:183-192.
29. Norlander S, Gustavsson BA, Lindell J, Nordgren B. Reduced mobility in the cervico-thoracic motion segment--a risk factor for musculoskeletal neck-shoulder pain: a two-year prospective follow-up study. *Scand J Rehabil Med*. 1997;29:167-174.
30. Papadonikolakis A, McKenna M, Warne W, Martin BI, Matsen FA, 3rd. Published evidence relevant to the diagnosis of impingement syndrome of the shoulder. *J Bone Joint Surg Am*. 2011;93:1827-1832.
31. Paris SV. A history of manipulative therapy through the ages and up to the current controversy in the United States. *Journal of Manual and Manipulative Therapy*. 2000;8:66-77.
32. Pope DP, Croft PR, Pritchard CM, Silman AJ, Macfarlane GJ. Occupational factors related to shoulder pain and disability. *Occup Environ Med*. 1997;54:316-321.
33. Portney LG, Watkins MP. *Foundations of clinical research : applications to practice*. Norwalk, Conn.: Appleton & Lange; 1993;509-516.
34. Roy JS, Moffet H, McFadyen BJ. The effects of unsupervised movement training with visual feedback on upper limb kinematic in persons with shoulder impingement syndrome. *J Electromyogr Kinesiol*. 2010;20:939-946.
35. Seitz AL, McClure PW, Finucane S, Boardman ND, 3rd, Michener LA. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? *Clin Biomech (Bristol, Avon)*. 2011;26:1-12.

36. Sobel JS, Winters JC, Groenier K, Arendzen JH, Meyboom de Jong B. Physical examination of the cervical spine and shoulder girdle in patients with shoulder complaints. *J Manipulative Physiol Ther.* 1997;20:257-262.
37. 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.
38. Sueki DG, Chaconas EJ. The effect of thoracic manipulation on shoulder pain: a regional interdependence model. *Phys Ther Rev.* 2011;16:399-408.
39. Theisen C, van Wagensveld A, Timmesfeld N, et al. Co-occurrence of outlet impingement syndrome of the shoulder and restricted range of motion in the thoracic spine--a prospective study with ultrasound-based motion analysis. *BMC Musculoskeletal Disord.* 2010;11:135[DOI 10.1186/1471-2474-11-135].
40. Veeger HE. The position of the rotation center of the glenohumeral joint. *J Biomech.* 2000;33:1711-1715.
41. 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.
42. Wu G, Cavanagh PR. ISB recommendations for standardization in the reporting of kinematic data. *J Biomech.* 1995;28:1257-1261.
43. 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.

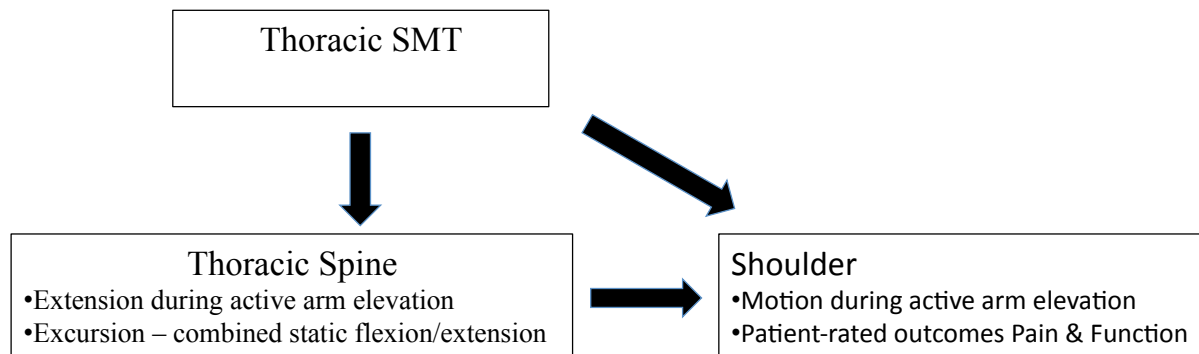


Figure 1. Theoretical framework for the mechanism of thoracic SMT. The primary purpose of this study is to assess whether changes to occur at the treated region (thoracic spine) and/or the affected region (shoulder), and if improved mobility at these regions relate to improved patient-rated outcomes of shoulder pain and function.

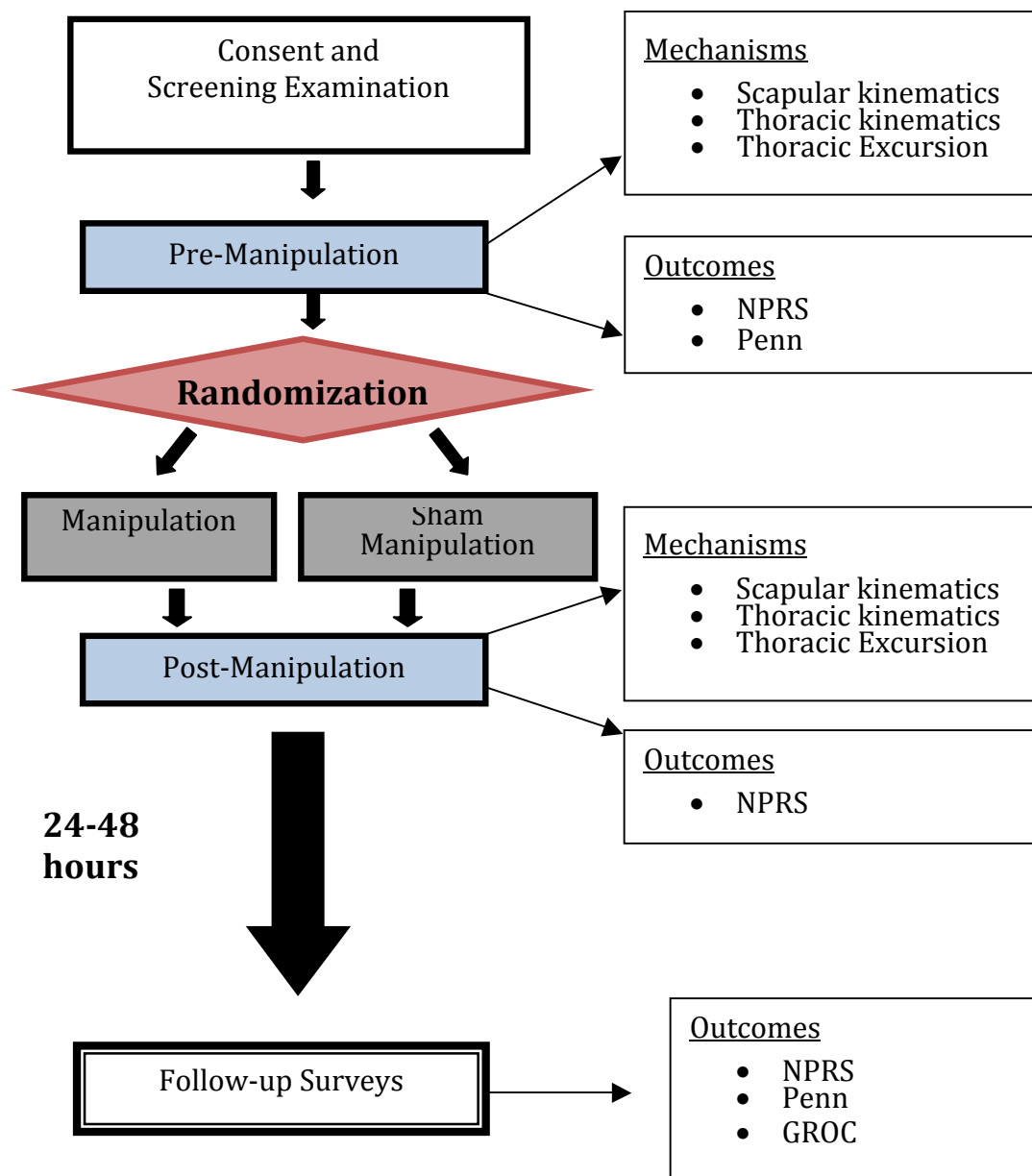
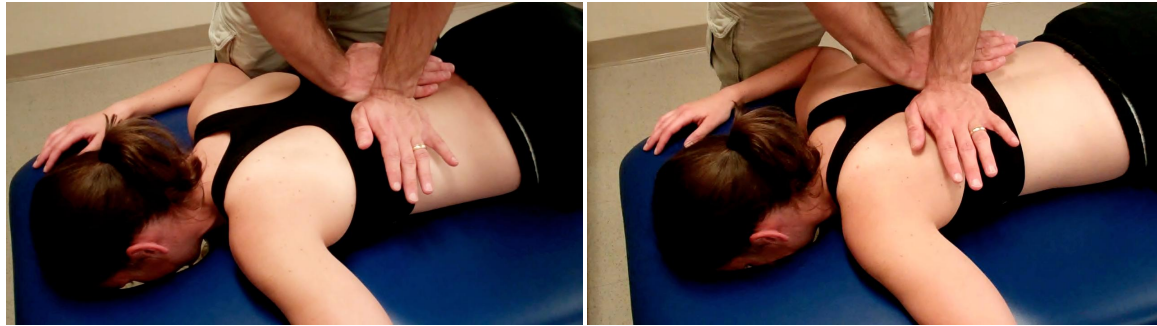
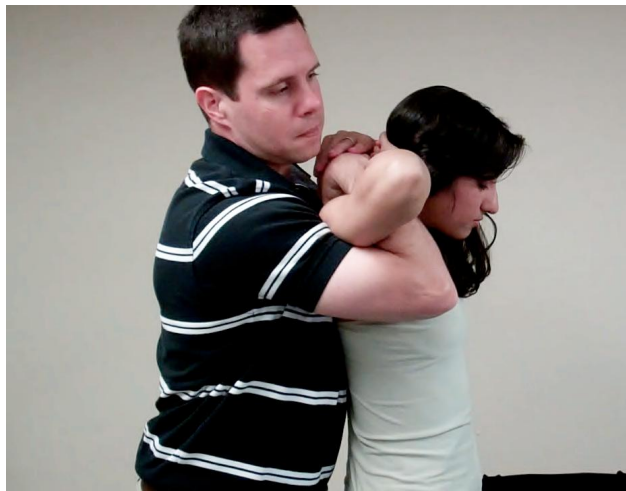


Figure 2. Flow diagram for experimental procedures. Abbreviations: NPRS = numeric pain rating scale, Penn = Penn Shoulder Scale, GROC = global rating of change



The mid and lower thoracic manipulation techniques are performed with the patient lying prone. The therapist positions the hypothenar eminence of his hands over the transverse processes of the thoracic vertebrae. This is at the level of T5 for the mid thoracic manipulation and at the level of T9 for the lower thoracic manipulation. The therapist asks the patient to inhale fully and exhale completely. The therapist follows the patient through the exhalation and applied a downward pressure to take out soft tissue slack. At the end of the exhalation, the therapist applies a high-velocity, low-amplitude thrust to achieve the manipulation.



The cervicothoracic junction manipulation is applied with the patient seated. The patient laces their fingers behind their neck. The therapist position is behind the patient. The therapist laces their arms through the patients arms and clasps their hands near the region of C7-T1. The patient applies one side of the chest as a fulcrum to the patients upper thoracic region. The patient is instructed to inhale, followed by a complete exhalation. The therapist takes out the soft tissue slack into thoracic extension as the patient exhales and applies a distracting high-velocity, low-amplitude thrust in the cephalad direction.

Figure 3. Images and descriptions of the thoracic SMT techniques utilized within this study.

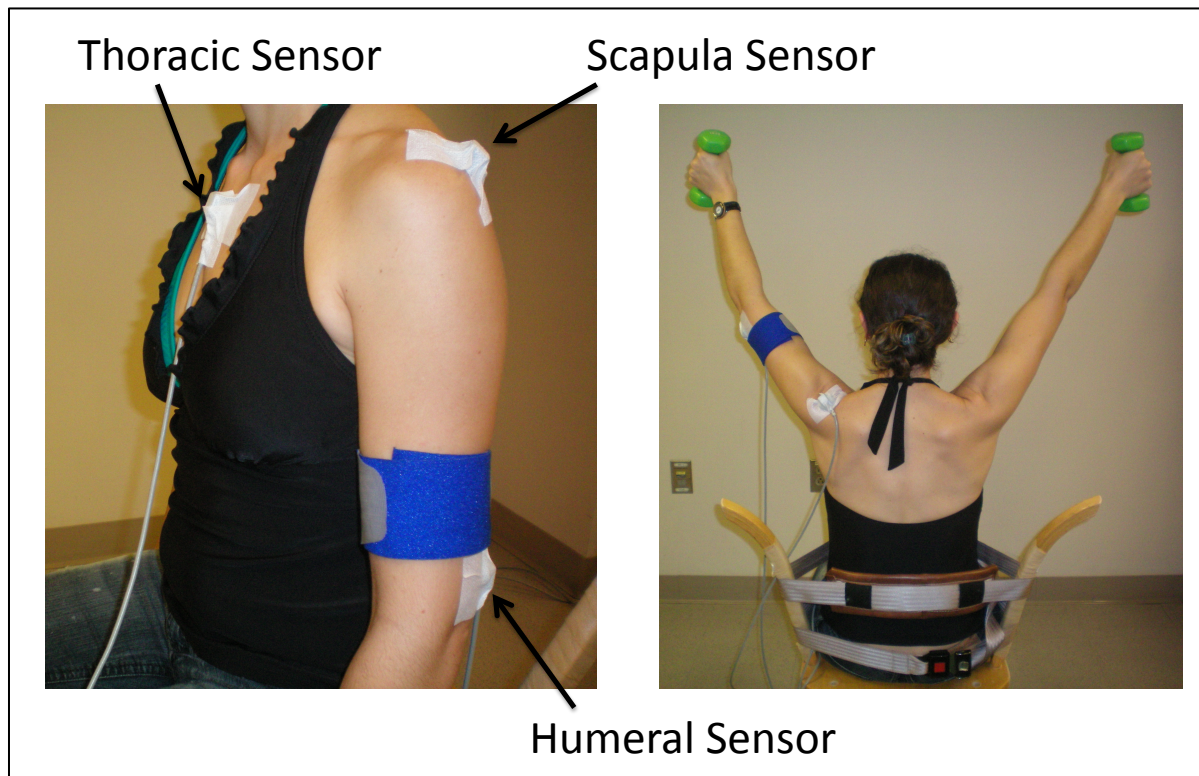


Figure 4. Electromagnetic sensor application and seated arm elevation testing position. Electromagnetic sensors applied to participant (left). The participant is in the seated position with belts applied (right).

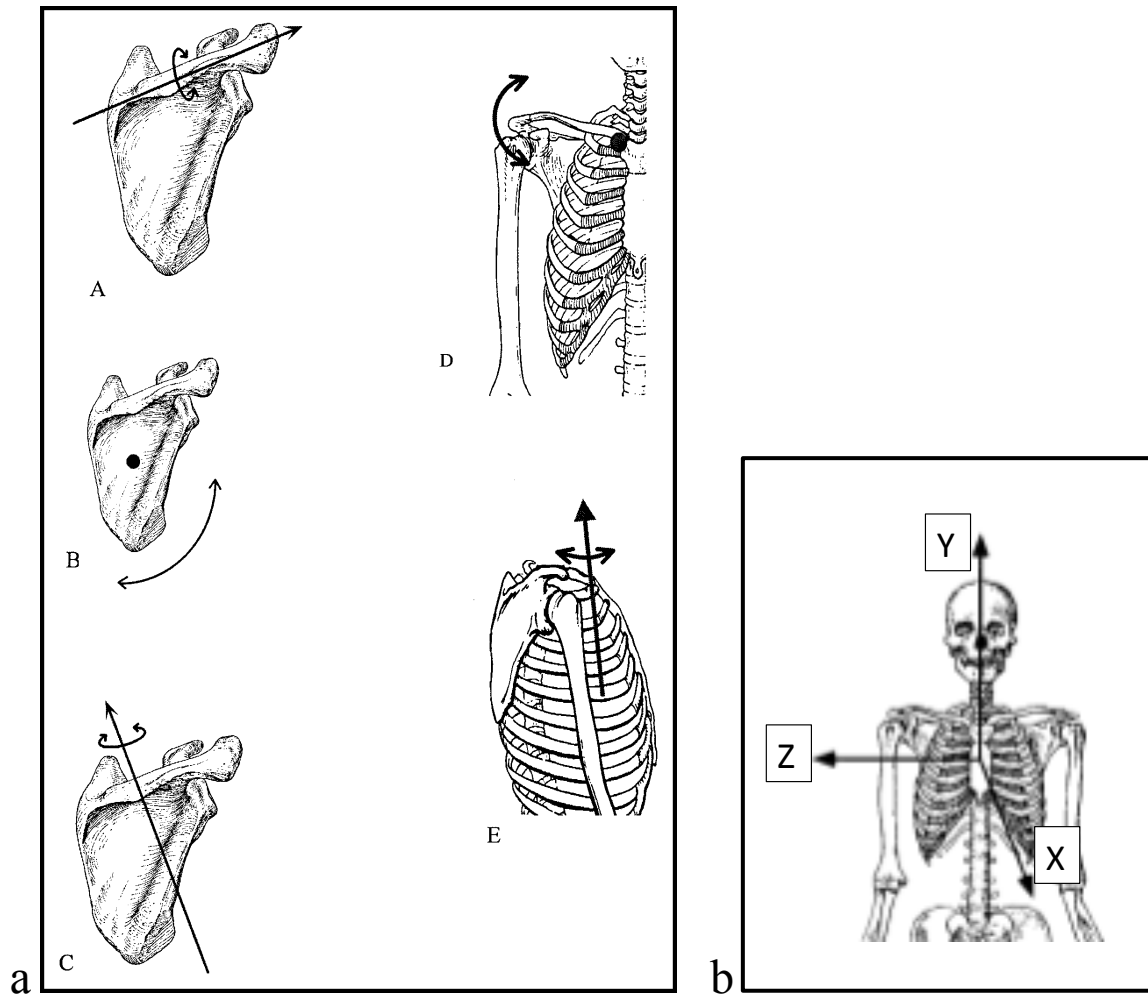


Figure 5.

a. The rotations and translations describing scapular motion (image taken from McClure et al. 2004).

- A. scapular anterior/posterior tilting
- B. scapular upward/downward rotation
- C. scapular internal/external rotation
- D. scapular (clavicular) elevation/depression
- E. scapular (clavicular) protraction/retraction

b. Thoracic flexion/extension occurs around axis coincident with the Z-axis of the global coordinate system. (image modified from McClure et al 2006).

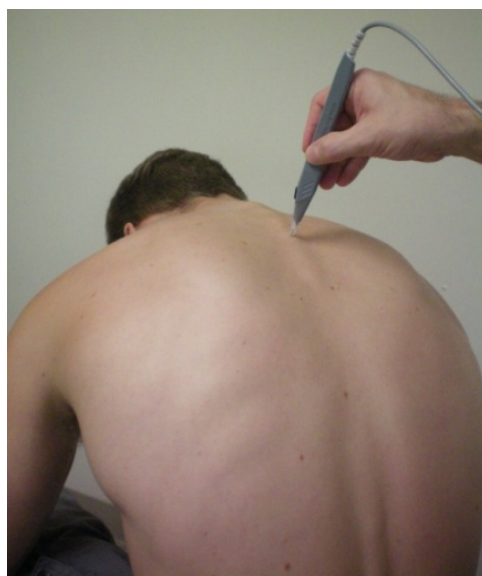


Figure 6. Digitization of the thoracic vertebrae using the 4th sensor (electromagnetic stylus).

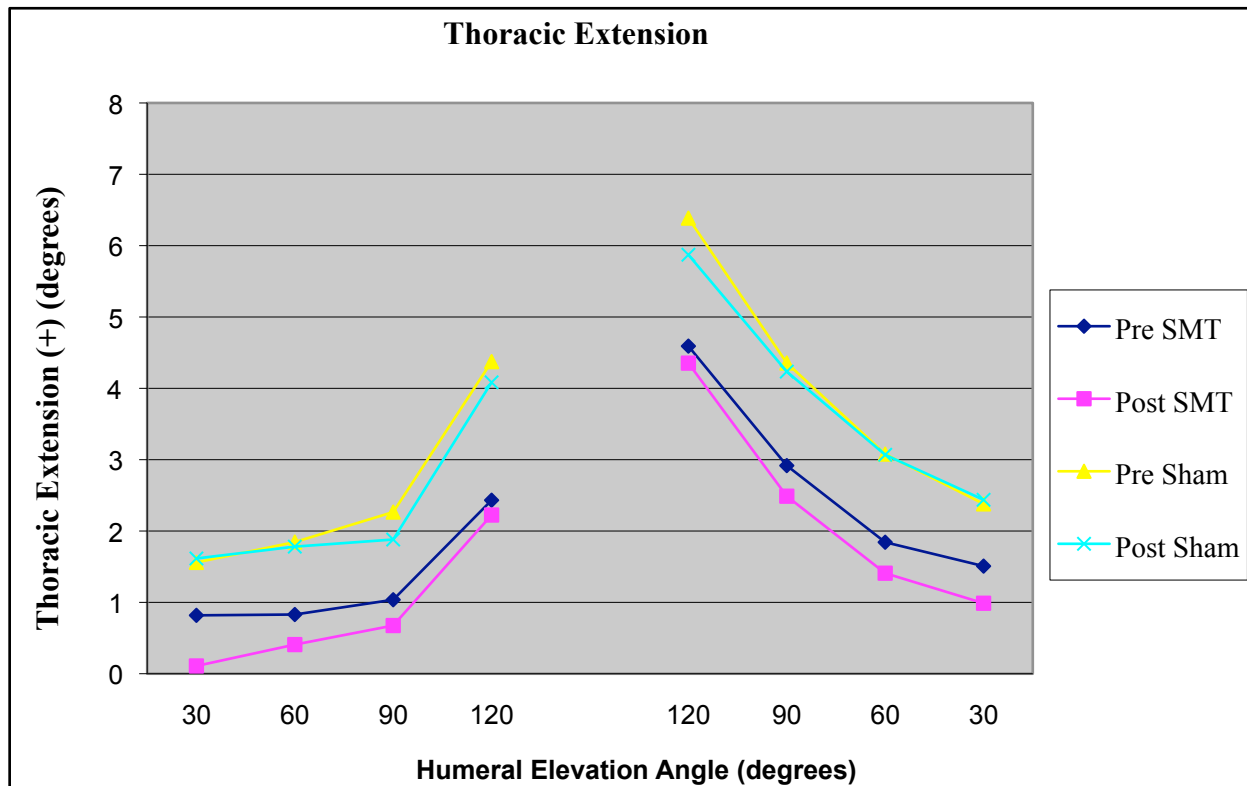


Figure 7. Thoracic extension during the ascending and descending phases of arm elevation

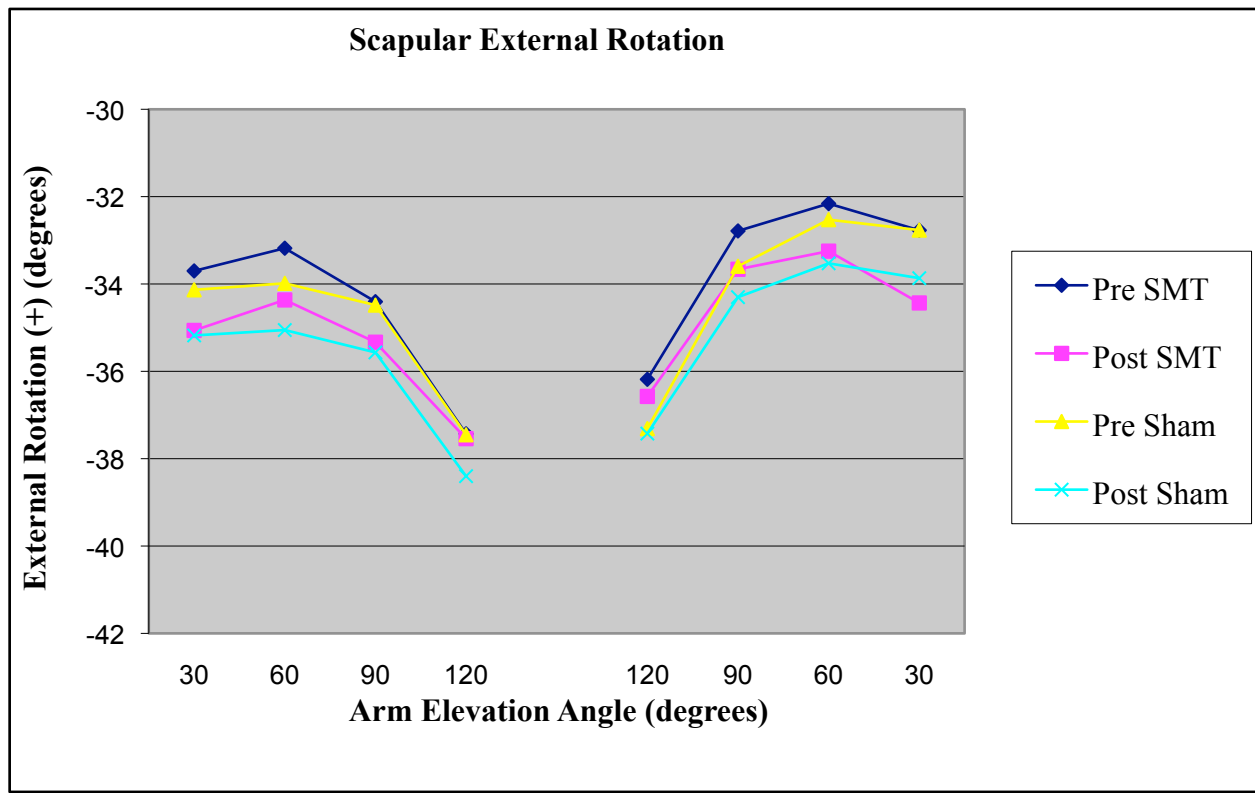


Figure 8. Scapular external rotation during the ascending and descending phases of arm elevation

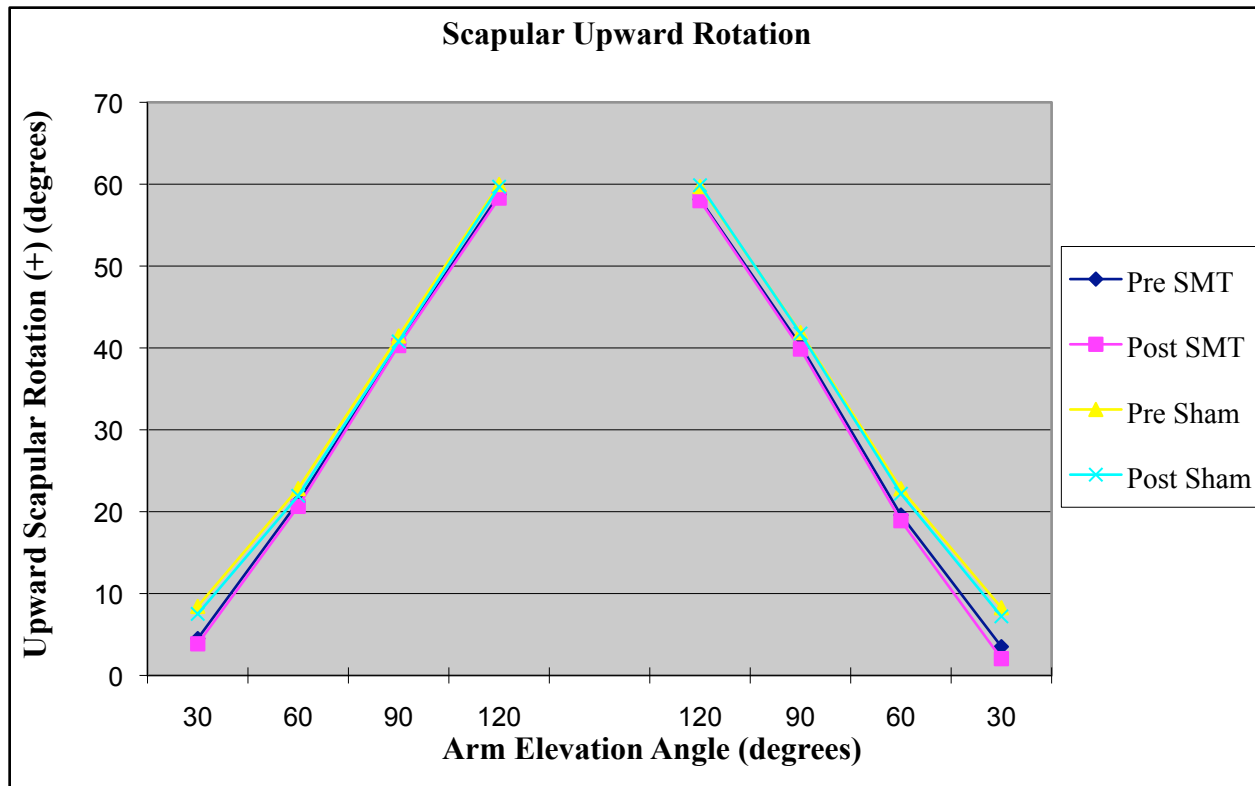


Figure 9. Scapular upward rotation during the ascending and descending phases of arm elevation

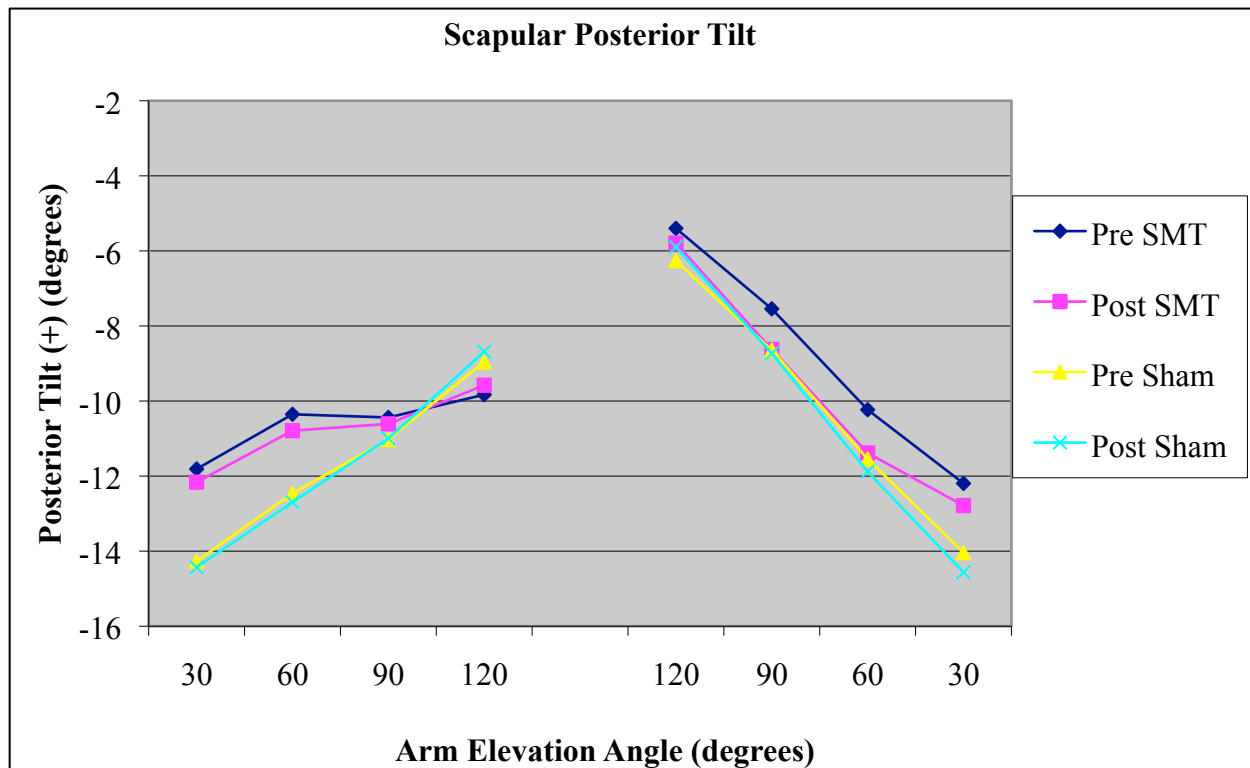


Figure 10. Scapular Posterior Tilt during the ascending and descending phases of arm elevation

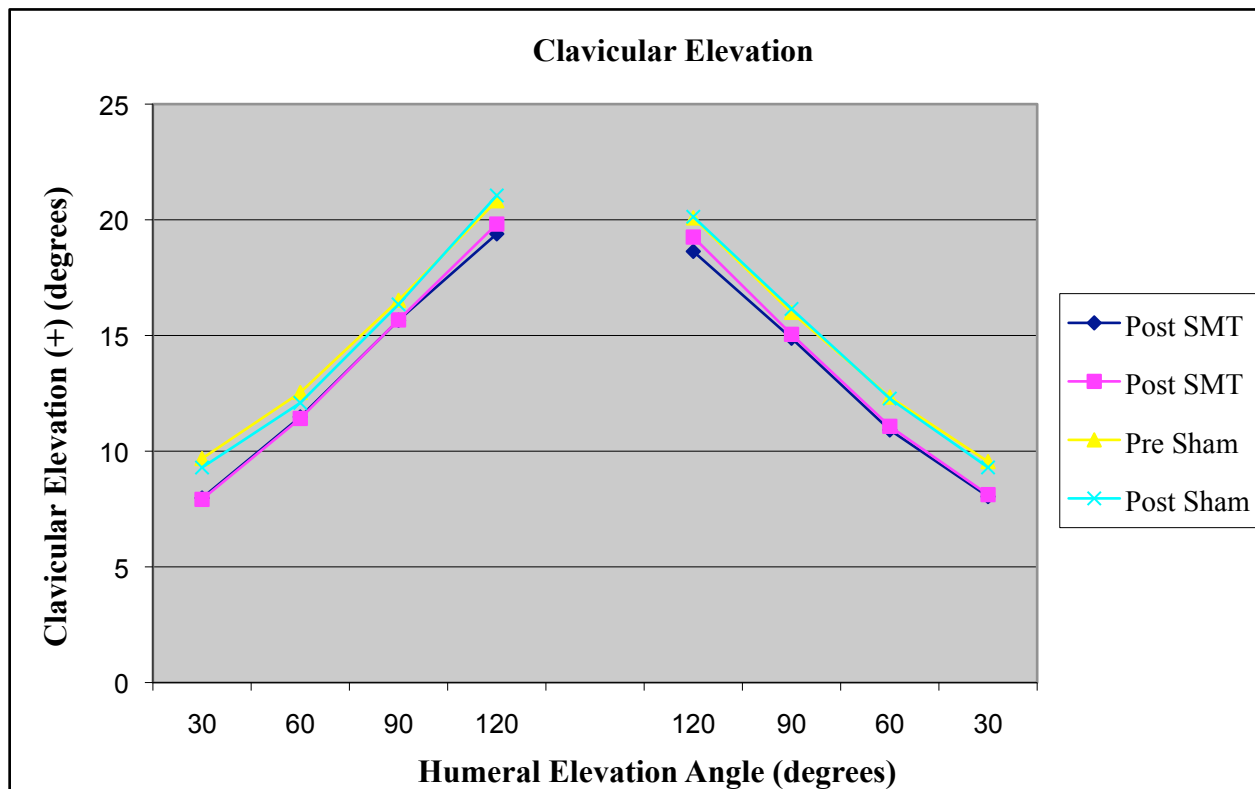


Figure 11. Clavicular elevation during the ascending and descending phase of arm elevation

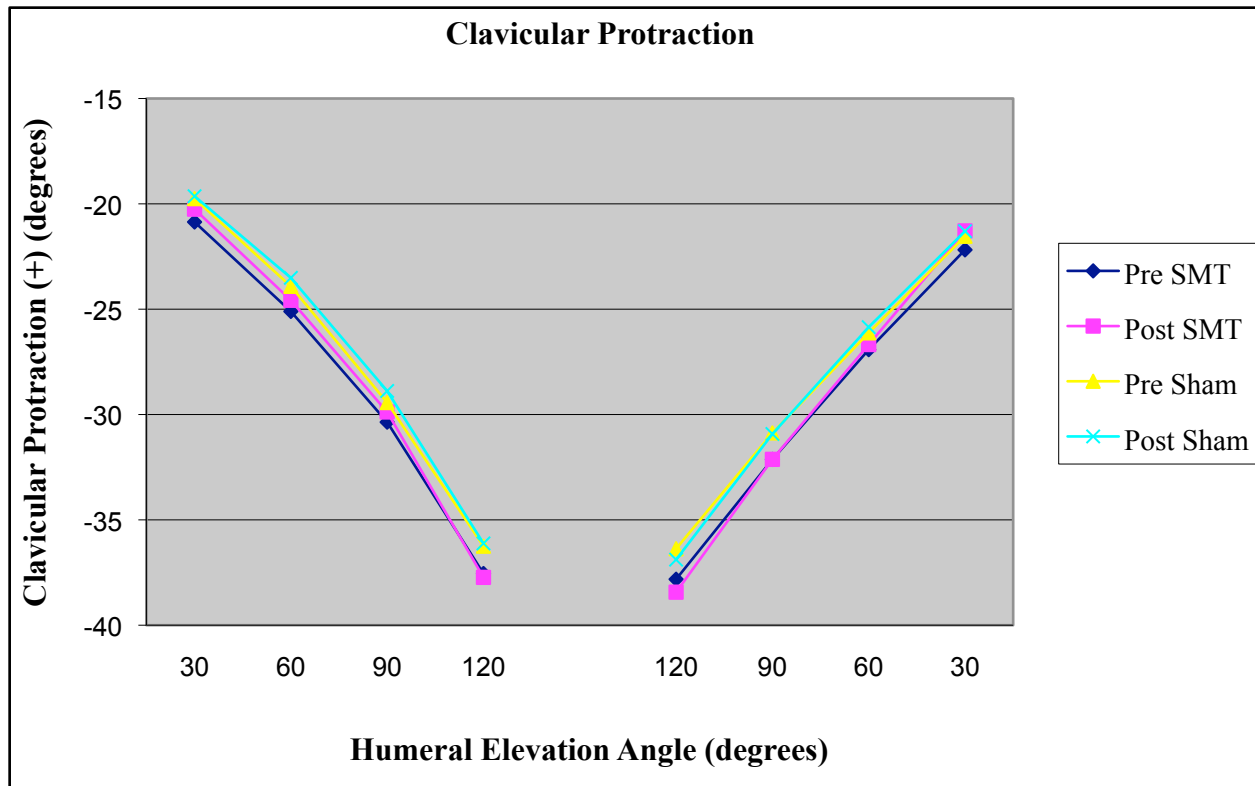


Figure 12. Clavicular protraction during the ascending and descending phases of arm elevation

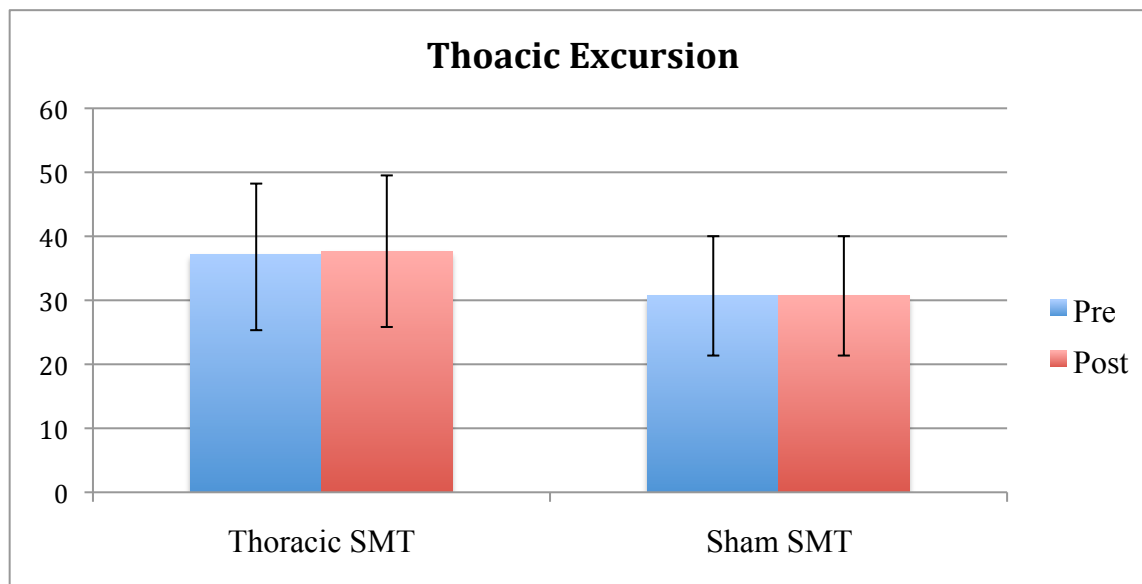


Figure 13. Thoracic excursion measurements for the thoracic SMT and sham SMT treatment groups prior to treatment (pre) and immediately following treatment (post).

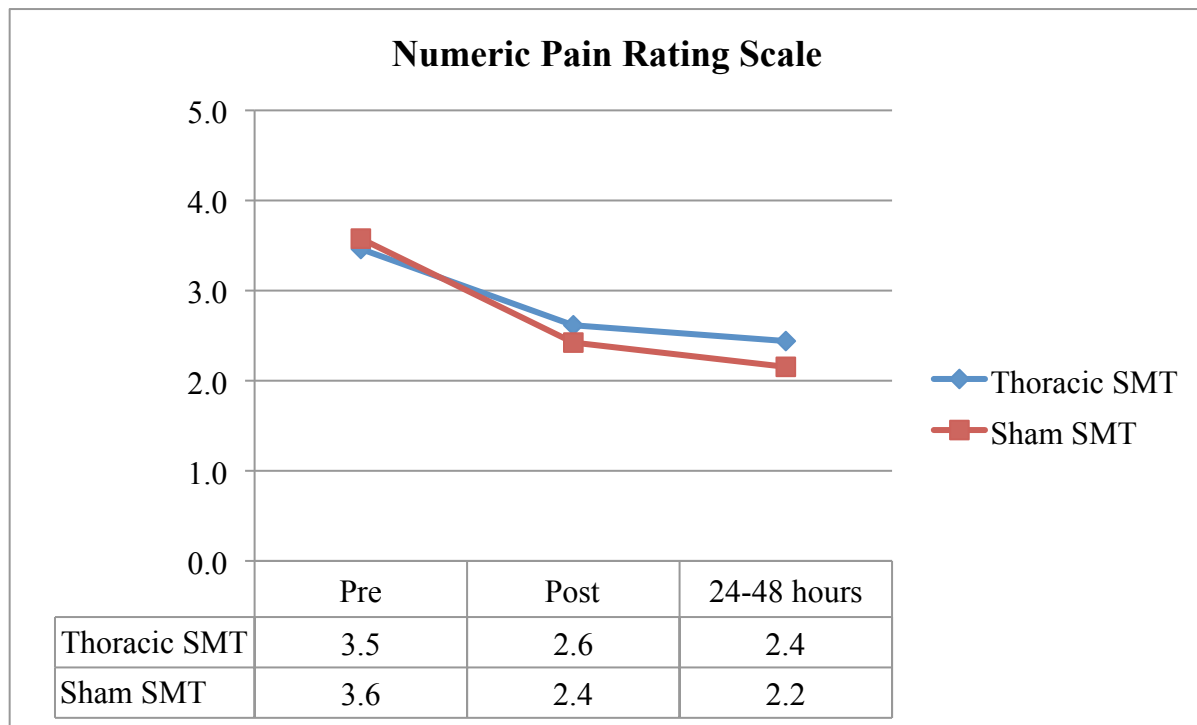


Figure 14. Patient-rated pain prior to treatment (pre), immediately following treatment (post), and 24-48 hours after treatment (24-48 hours).

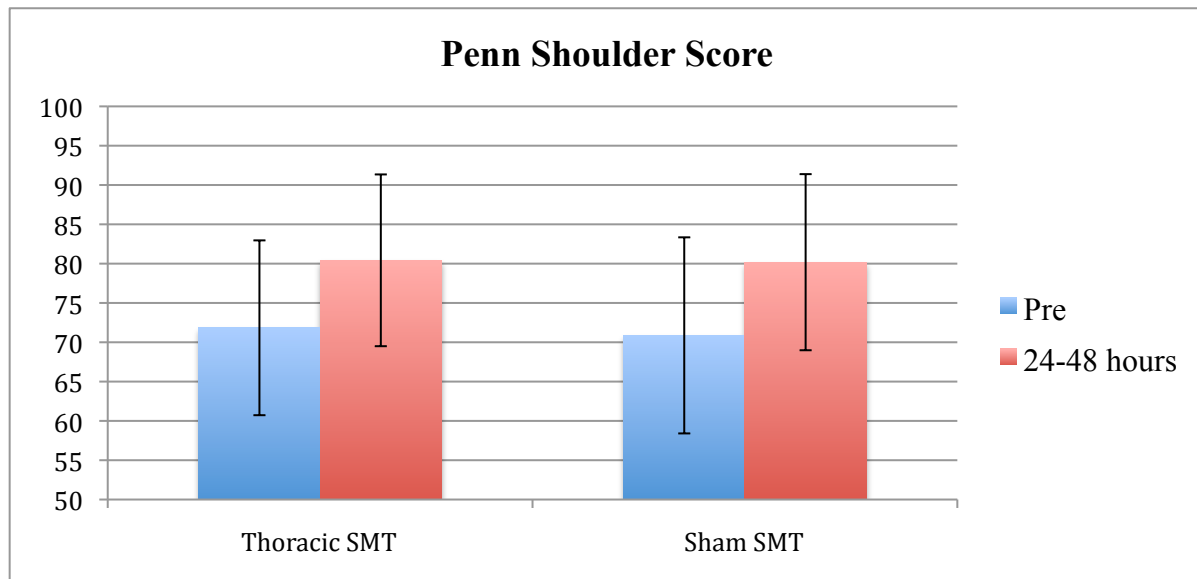


Figure 15. Penn Shoulder Score for both treatment groups pre-treatment (Pre) and at 24-48 hours after treatment (24-48 hours).

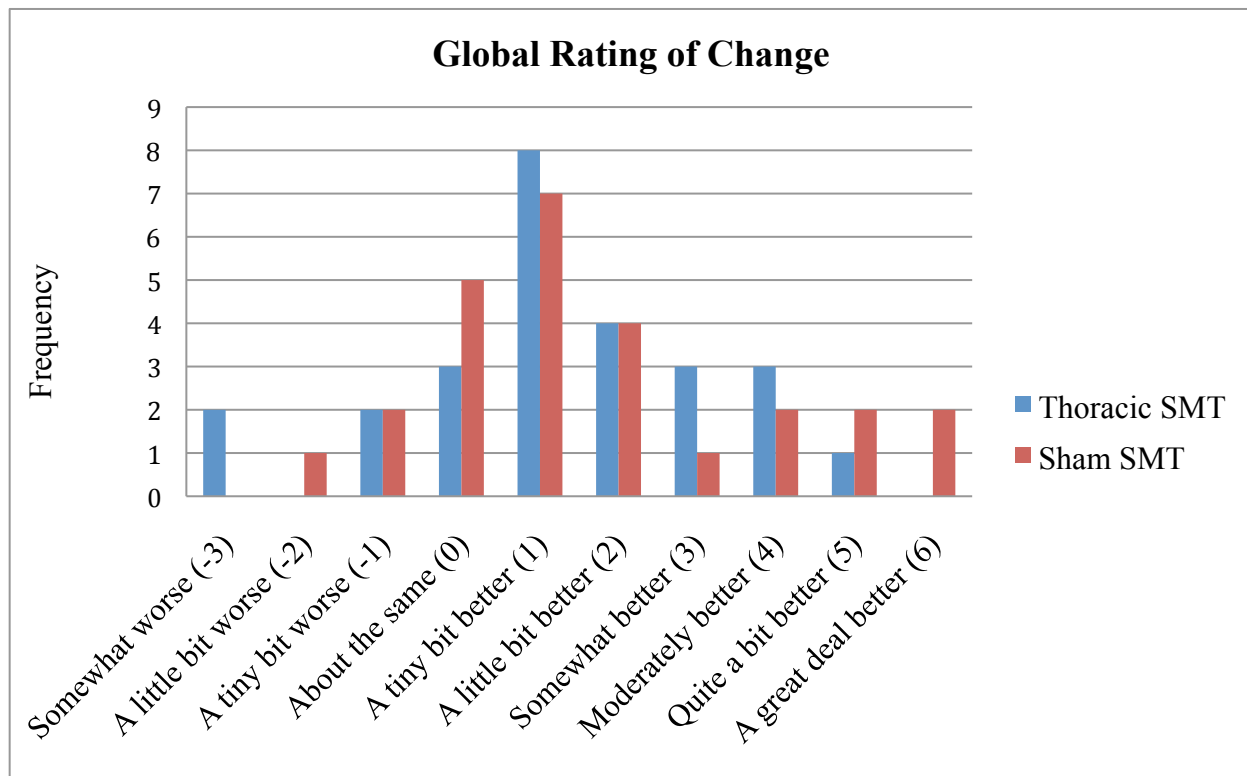


Figure 16. Frequency of responses on the Global Rating of Change (GROC) questionnaire.

Table 1. Participant Characteristics. SMT = thoracic spinal manipulative therapy, sham SMT = sham spinal manipulative therapy

	SMT (n=26)	Sham SMT (n=26)	p-value
Age (years) range	30.8 ± 11.9 18-59	33.2 ± 12.6 18-59	p = 0.49
Symptom duration (months)	38.3 ± 63.6	38.3 ± 51.6	p > 0.99
Acute/ Subacute (0 -12 weeks)	3 (12%)	3 (12%)	
Chronic (> 12 weeks)	23 (88%)	23 (88%)	
Dominant shoulder tested , n (%)	12 (46%)	18 (69%)	p = 0.16
Female, n (%)	15 (58%)	9 (34.6%)	p = 0.16
BMI (kg/ m ²) Range	25.7 ± 5.7 18.2-39.6	26.8 ± 5.8 19.6-40.5	p = 0.51

Table 2. Thoracic kinematics data for extension (during arm elevation task) and excursion. Extension was measured during the arm elevation task. Units are in degrees, with standard deviation. Positive values indicate greater extension or greater excursion.

Thoracic Extension				
Humeral Angle	Thoracic SMT		Sham SMT	
	Pre-Treatment	Post-Treatment	Pre-Treatment	Post-Treatment
Rest	0.5 ± 6.0	0.0 ± 5.7	1.5 ± 5.7	1.2 ± 6.2
Ascending				
30°	0.6 ± 5.8	0.1 ± 5.5	1.6 ± 5.7	1.6 ± 6.1
60°	0.8 ± 5.4	0.4 ± 5.1	1.8 ± 5.6	1.8 ± 6.1
90°	1.0 ± 5.6	0.7 ± 5.4	2.3 ± 5.4	1.9 ± 6.1
120°	2.4 ± 5.8	2.2 ± 5.7	4.4 ± 5.4	4.1 ± 6.1
Descending				
120°	4.6 ± 5.4	4.4 ± 4.8	6.4 ± 5.5	5.9 ± 5.8
90°	2.9 ± 5.1	2.5 ± 4.5	4.4 ± 5.5	4.2 ± 5.6
60°	1.8 ± 5.2	1.4 ± 4.7	3.1 ± 5.3	3.1 ± 5.7
30°	1.5 ± 5.6	1.0 ± 5.3	2.4 ± 5.3	2.4 ± 5.9

Thoracic Excursion			
Treatment Group	Pre-Treatment	Post-Treatment	Pre-Post Difference
Thoracic SMT	37.17 ± 11.06	37.67 ± 11.84	0.50 ± 7.16
Sham SMT	30.69 ± 9.33	31.65 ± 10.16	0.96 ± 4.14

Table 3. Pre-treatment and post-treatment scapular external rotation angles during the arm elevation task. Values are in degrees \pm standard deviation. Negative values represent an internally rotated position; changes in the negative direction represent internal rotation and changes in the positive direction represent external rotation.

Scapular External Rotation					
Humeral Angle	Thoracic SMT		Sham SMT		
	Pre-Treatment	Post-Treatment	Pre-Treatment	Post-Treatment	
Rest	-35.2 \pm 6.2	-36.2 \pm 6.2	-34.6 \pm 7.5	-35.6 \pm 7.9	
Ascending					
30°	-33.9 \pm 5.9	-35.1 \pm 6.0	-34.1 \pm 7.3	-35.2 \pm 7.8	
60°	-33.3 \pm 6.3	-34.4 \pm 6.5	-34.0 \pm 7.8	-35.1 \pm 8.2	
90°	-34.4 \pm 6.8	-35.3 \pm 7.3	-34.5 \pm 8.4	-35.6 \pm 9.2	
120°	-37.3 \pm 10.7	-37.5 \pm 9.8	-37.5 \pm 9.6	-38.4 \pm 10.6	
Descending					
120°	-36.4 \pm 12.1	-36.6 \pm 11.4	-37.3 \pm 11.4	-37.4 \pm 11.2	
90°	-32.9 \pm 7.2	-33.7 \pm 7.4	-33.6 \pm 9.2	-34.3 \pm 9.5	
60°	-32.3 \pm 6.6	-33.2 \pm 6.5	-32.5 \pm 8.8	-33.5 \pm 9.0	
30°	-33.1 \pm 6.7	-34.4 \pm 6.2	-32.8 \pm 8.0	-33.9 \pm 8.2	

Table 4. Pre-treatment and post-treatment scapular upward rotation angles during the arm elevation task. Values are in degrees \pm standard deviation. Positive values indicate greater upward rotation.

Scapular Upward Rotation					
Humeral Angle	Thoracic SMT		Sham SMT		
	Pre-Treatment		Post-Treatment		
Rest	-1.1	± 8.6	-1.6	± 8.0	4.9 ± 10.5
Ascending					4.4 ± 11.6
30°	4.3	± 9.6	3.9	± 8.4	8.4 ± 9.4
60°	21.1	± 9.6	20.7	± 8.9	22.8 ± 7.7
90°	40.4	± 10.3	40.3	± 9.9	41.5 ± 7.0
120°	58.6	± 11.8	58.3	± 12.0	60.0 ± 8.6
Descending					59.7 ± 8.9
120°	58.1	± 12.7	58.0	± 12.9	59.7 ± 9.4
90°	40.3	± 11.4	39.9	± 11.0	41.9 ± 7.5
60°	19.6	± 11.8	18.9	± 11.4	22.8 ± 7.9
30°	3.3	± 10.6	2.1	± 9.7	8.3 ± 9.3
					7.2 ± 10.0

Table 5. Pre-treatment and post-treatment scapular posterior tilt angles during the arm elevation task. Values are in degrees \pm standard deviation. Positive values indicate greater posterior tilting.

Scapular Posterior Tilt						
Humeral Angle	Thoracic SMT			Sham SMT		
	Pre-Treatment		Post-Treatment	Pre-Treatment		Post-Treatment
Rest	-13.2	± 7.0	-13.3 ± 7.1	-15.6	± 6.9	-16.0 ± 7.1
Ascending						
30°	-11.9	± 6.9	-12.2 ± 6.9	-14.3	± 6.5	-14.4 ± 6.9
60°	-10.6	± 6.9	-10.8 ± 7.1	-12.5	± 7.1	-12.7 ± 7.4
90°	-10.8	± 7.5	-10.6 ± 7.7	-11.0	± 7.9	-11.0 ± 8.4
120°	-10.2	± 10.1	-9.6 ± 9.9	-9.0	± 8.6	-8.7 ± 8.7
Descending						
120°	-5.8	± 10.5	-5.8 ± 9.9	-6.3	± 8.5	-5.9 ± 8.8
90°	-7.9	± 7.7	-8.6 ± 7.8	-8.6	± 7.7	-8.7 ± 8.0
60°	-10.5	± 7.3	-11.4 ± 7.6	-11.5	± 7.2	-11.9 ± 7.0
30°	-12.3	± 6.5	-12.8 ± 7.0	-14.0	± 6.4	-14.6 ± 6.1

Table 6. Pre-treatment and post-treatment clavicular elevation angles during the arm elevation task. Values are in degrees \pm standard deviation. Positive values indicate greater elevation.

Clavicular Elevation					
Humeral Angle	Thoracic SMT		Sham SMT		
	Pre-Treatment	Post-Treatment	Pre-Treatment	Post-Treatment	
Rest	7.5 \pm 3.7	7.2 \pm 3.9	9.3 \pm 5.9	9.1 \pm 5.9	
Ascending					
30°	8.2 \pm 3.6	7.9 \pm 3.9	9.7 \pm 5.9	9.3 \pm 5.8	
60°	11.7 \pm 3.9	11.4 \pm 4.2	12.5 \pm 5.5	12.1 \pm 5.3	
90°	15.9 \pm 4.6	15.7 \pm 4.9	16.5 \pm 5.1	16.3 \pm 5.1	
120°	19.6 \pm 4.9	19.8 \pm 5.2	20.8 \pm 5.4	20.1 \pm 5.1	
Descending					
120°	18.9 \pm 5.8	19.3 \pm 6.3	20.1 \pm 5.6	20.1 \pm 5.1	
90°	15.2 \pm 4.9	15.1 \pm 5.5	16.0 \pm 5.1	16.1 \pm 5.1	
60°	11.2 \pm 4.6	11.1 \pm 5.0	12.3 \pm 5.1	12.3 \pm 5.2	
30°	8.2 \pm 3.9	8.1 \pm 4.4	9.6 \pm 5.4	9.3 \pm 5.6	

Table 7. Pre-treatment and post-treatment clavicular protraction angles during the arm elevation task. Values are in degrees \pm standard deviation. Positive values indicate greater protraction.

Clavicular Protraction					
Humeral Angle	Thoracic SMT		Sham SMT		
Ascending	Pre-Treatment	Post-Treatment	Pre-Treatment	Post-Treatment	
Rest	-18.3 \pm 5.4	-18.0 \pm 4.7	-17.5 \pm 5.8	-17.4 \pm 5.6	
Ascending					
30°	-20.8 \pm 4.9	-20.3 \pm 4.6	-19.8 \pm 5.6	-19.6 \pm 5.3	
60°	-25.2 \pm 4.8	-24.6 \pm 4.8	-23.9 \pm 5.6	-23.5 \pm 5.4	
90°	-30.4 \pm 4.6	-29.9 \pm 5.0	-29.4 \pm 5.6	-28.9 \pm 5.6	
120°	-37.6 \pm 5.7	-37.7 \pm 5.4	-36.2 \pm 6.2	-36.1 \pm 6.3	
Descending					
120°	-37.9 \pm 6.2	-38.4 \pm 5.8	-36.4 \pm 6.2	-36.9 \pm 5.8	
90°	-32.2 \pm 5.5	-32.1 \pm 5.4	-30.9 \pm 6.1	-30.9 \pm 5.3	
60°	-26.9 \pm 5.3	-26.7 \pm 5.3	-26.1 \pm 6.1	-25.9 \pm 5.6	
30°	-22.1 \pm 5.4	-21.3 \pm 5.0	-21.5 \pm 5.8	-21.3 \pm 5.5	

Table 8. Patient-rated outcomes on the numeric rating of pain scale (NPRS), Penn Shoulder Score (Penn), and global rating of change (GROC). Time points for ratings are indicated as pre-treatment (Pre), post-treatment (Post), and 24-48 hour follow-up (24-48 hours). The scores (\pm standard deviation) are reported for each group. Score range is indicated next to each outcome instrument.

	Pre-treatment	Post-treatment	24-48 hours after treatment
NPRS (0-10)			
Thoracic SMT	3.5 \pm 1.4	2.6 \pm 1.8	2.4 \pm 1.6
Sham SMT	3.6 \pm 1.4	2.4 \pm 2.0	2.2 \pm 1.5
Penn (0-100)			
Thoracic SMT	71.8 \pm 11.1		80.4 \pm 10.9
Sham SMT	70.9 \pm 12.5		80.2 \pm 11.2
GROC (-7 to 7)			
Thoracic SMT			1.4 \pm 2.0
Sham SMT			1.7 \pm 2.2

Table 9. Thoracic and Scapular Kinematics . Results from statistical analysis of kinematics variables measured during the ascending and descending phases of the arm elevation task.

* denotes statistical significance.

Abbreviations: ER = scapular external rotation, UR = scapular upward rotation, PT = scapular posterior tilt, CE = clavicular elevation, CP = clavicular protraction, Thor Ext = thoracic extension.

Factors	Thor Ext Ascending			Thor Ext Descending		ER Ascending		ER Descending	
	df	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value
group	1, 50	0.278	0.601	1.131	0.293	0.033	0.857	0.023	0.881
Time	1, 350	1.770	0.185	1.772	0.184	9.163	0.003*	4.200	0.041*
Group x Time	1, 350	0.085	0.771	0.391	0.532	0.087	0.768	0.012	0.914
Arm Angle	3, 350	22.731	<0.001*	55.067	<0.001*	25.936	<0.001*	23.099	<0.001*
Group x Arm Angle	3, 350	0.538	0.657	0.282	0.838	0.179	0.911	0.626	0.598
Time x Arm Angle	3, 350	0.050	0.985	0.029	0.993	0.149	0.931	0.353	0.787
Group x Time x Arm Angle	3, 350	0.011	0.998	0.202	0.895	0.090	0.966	0.007	0.999

Factors	UR Ascending			UR Descending		PT Ascending		PT Descending	
	df	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value
group	1, 50	0.657	0.422	1.313	0.257	0.180	0.673	0.154	0.696
Time	1, 350	1.515	0.219	1.480	0.225	0.009	0.925	1.065	0.303
Group x Time	1, 350	0.176	0.675	0.081	0.776	0.030	0.863	0.304	0.582
Arm Angle	3, 350	3100.810	<0.001*	2994.243	<0.001*	30.036	<0.001*	113.747	<0.001*
Group x Arm Angle	3, 350	2.707	0.045*	3.405	0.008*	7.083	<0.001*	1.181	0.317
Time x Arm Angle	3, 350	0.067	0.977	0.358	0.783	0.295	0.829	0.333	0.801
Group x Time x Arm Angle	3, 350	0.026	0.994	0.003	0.999	0.028	0.994	0.057	0.982

Factors	CE Ascending			CE Descending		CP Ascending		CP Descending	
	df	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value
group	1, 50	0.614	0.437	0.646	0.426	0.685	0.412	0.451	0.505
Time	1, 350	1.021	0.313	0.017	0.895	2.392	0.123	0.094	0.759
Group x Time	1, 350	0.017	0.896	0.001	0.974	0.057	0.812	0.132	0.717
Arm Angle	3, 350	863.406	<0.001*	707.002	<0.001*	1009.830	<0.001*	880.674	<0.001*
Group x Arm Angle	3, 350	1.197	0.311	0.139	0.937	0.382	0.766	1.498	0.215
Time x Arm Angle	3, 350	0.590	0.622	0.198	0.898	0.270	0.847	0.917	0.433
Group x Time x Arm Angle	3, 350	0.022	0.996	0.109	0.955	0.094	0.963	0.084	0.969

Table 10. Results from statistical analysis of thoracic excursion and patient-rated outcomes of pain (NPRS) and function (Penn).

* denotes statistically significance

Thoracic Excursion			
Factors	df	F Ratio	p-value
Group	1, 50	4.858	0.032*
Time	1, 50	0.804	0.343
Group x Time	1, 50	0.080	0.779

Numeric Pain Rating Scale (NPRS)			
Factor	df	F Ratio	p-value
group	1, 50.08	0.105	0.747
Time	2, 99.38	13.062	<0.001*
group*Time	2, 99.38	0.308	0.735

Penn Shoulder Score (Penn)			
Factor	df	F Ratio	p-value
group	1, 49.87	0.072	0.790
Time	1, 49.18	51.154	<0.001*
group*Time	1, 49.18	0.021	0.886

Appendix 1. Joint coordinate systems and motion calculation for the thorax, clavicle, scapula, and humerus.

Digitized anatomical land marks

Thorax:	C7 – spinous process of 7 th cervical vertebra T7 – spinous process of 7 th thoracic vertebra SN – suprasternal notch XP – xiphoid process
Clavicle:	AC – acromioclavicular joint Proximal reference - SN
Scapula:	TS – Trigonum Spinae Scapulae (root of the spine of the scapula) IA – inferior angle of the scapula AA – acromial angle (most laterodorsal point)
Humerus:	GH – center of rotation for the humeral head EL – lateral epicondyle EM – medial epicondyle

GH is not digitized directly. This point is calculated by moving the humerus through short arcs of motion and finding the pivot point of the instantaneous helical axes (IHA) using a least squares calculation. The GH is calculated in relation to the scapular sensor.

Coordinate systems

Thorax:	Origin – SN Y-axis – line through the midpoint between XP and T7 and the midpoint between SN and C7 (positive upward) Z-axis – line perpendicular to the plane formed by SN, C7, and the midpoint between XP and T7 (positive to the right) X-axis – line perpendicular to Z and Y (positive forward)
Clavicle	Origin – SN Z-axis – line connecting SN and AC (positive toward AC) X-axis – line perpendicular to Z-axis of clavicle and Y-axis of thorax Y-axis – line perpendicular to the X- and Z-axes of clavicle (positive upward)
Scapula	Origin - AA Z-axis – line through TS and AA (positive toward AA) X-axis – line perpendicular to the plane through IA, AA, and TS (positive forward) Y-axis – line perpendicular to the X- and Z-axes (positive upward)

Humerus Origin – GH
 Y-axis – line through GH and the midpoint of EL and EM (positive toward GH)
 X-axis – line perpendicular to the plane through EL, EM, and GH (positive forward)
 Z-axis – line perpendicular to Y and Z axes (positive right)

Euler angle sequence of rotations

Thorax Motion of thorax relative to the global coordinate system (Z-X-Y order)
 Z – rotation around the axis coincident with the global Z-axis; flexion (negative), extension (positive)
 X – rotation around the axis coincident with the thoracic X-axis; lateral flexion right (positive) and left (negative)
 Y – rotation around the axis coincident with the thoracic Y-axis; axial rotation right (negative) and left (positive)

Clavicle Motion of the clavicle relative to the thorax (Y-X-Z)
 Y – rotation around the axis coincident with the Y-axis of the thorax; retraction (negative), protraction (positive)
 X – rotation around the axis coincident with the X-axis of the clavicle; elevation (negative), depression (positive)
 Z – rotation around the axis coincident with the Z-axis of the clavicle; axial rotation of the clavicle backward (positive) and forward (negative)

Scapula Motion of the scapula relative to the thorax (Y-X-Z order)
 Y – rotation around the axis coincident with the Y-axis of the thorax; retraction (negative), protraction (positive)
 X – rotation around the axis coincident with the X-axis of the scapula; lateral (negative), medial (positive)
 Z - rotation around the axis coincident with the Z-axis of the scapula; anterior tip (negative), posterior tip (positive)

Humerus Motion for the humerus relative to the thorax (Y-X-Y order)
 Y – rotation around the axis coincident with the Y-axis of the thorax; plane of elevation is 0° in abduction and 90° in forward flexion
 X – rotation around the axis coincident with the humeral X-axis; elevation
 Y – rotation around the Y-axis of the humerus; internal rotation (positive), external rotation (negative)

Appendix 2. Calculation of the thoracic flexion and extension angles used for thoracic excursion.

Digitized Points

Spinous processes of T1-4 and T9-12

Plane of Motion

Coincident with the Z-Y plane of the global coordinate system

Calculation of thoracic spinal angle

Upper thoracic segment - best-fit line (1st order polynomial) through T1-4

Lower thoracic segment - best-fit line (1st order polynomial) through T9-12

m1 = slope of upper segment in the global Z-Y plane

m2 = slope of the lower segment in the global Z-Y plane

ϕ = thoracic spinal angle; calculated using the equation:

$$\phi = \tan^{-1} \left(\frac{m2 - m1}{1 + (m1 \bullet m2)} \right)$$

Thoracic excursion = (flexion angle) – (extension angle)

Chapter 4. Immediate Changes in Pressure Pain Sensitivity after Thoracic Spinal Manipulative Therapy in Patients with Subacromial Pain Syndrome

Abstract

Study Design: Randomized Controlled Laboratory Study

Objectives: To assess the immediate neurophysiologic pain response in patients with unilateral shoulder pain following thoracic spinal manipulative therapy (SMT) using pressure pain threshold (PPT), and secondarily to assess the relationship of change in pain sensitivity to patient-rated outcomes of pain and function following treatment.

Background: Thoracic SMT can improve symptoms in patients with subacromial pain syndrome however, the mechanisms of SMT are not well established. Changes in pain modulation may account for the benefits of SMT. Elucidating mechanisms will aid the directed use of thoracic SMT for treating patients with shoulder pain.

Methods: Subjects with unilateral subacromial pain syndrome (n=45) were randomly assigned to receive treatment with SMT or sham SMT directed at the upper, middle, and lower thoracic spine. PPT was measured at the painful shoulder (deltoid) and unaffected regions (contralateral deltoid and bilateral lower trapezius areas) immediately pre- and post-treatment. PPT measures at the painful shoulder were used to assess peripheral and/or central pain sensitivity, and PPT at unaffected regions measured central pain sensitivity. Patient-rated outcomes were pain (numeric

pain rating scale - NPRS), function (Pennsylvania Shoulder Score - Penn), and global rating of change (GROC).

Results: There were no significant differences between or within groups in the PPT measures ($p \geq 0.372$). Outcomes improved in both groups for NPRS, Penn and GROC ($p < 0.001$), but there were no differences between the thoracic SMT or sham SMT groups ($p \geq 0.574$). For both groups combined, the NPRS decreased 1.1 [95% CI = 0.6, 1.6] points from pre- to post-treatment, and 1.5 [95% CI = 0.9, 2.0] points from pre-treatment to the 24-48 hour follow-up. Penn scores improved across the groups 10.1 [95% CI = 7.3, 12.9] points from pre-treatment to 24-48 hour follow-up. There was one moderate correlation ($r=0.52$, $p=0.009$) between the change in PPT at the unaffected lower trapezius and baseline Penn score in the SMT group.

Conclusion: Thoracic SMT did not improve peripheral or central pain sensitivity as measured by PPT. Both groups had improved patient-rated pain and function within 24-48 hours of treatment, but outcomes were not greater in the SMT group. Interestingly, there was a positive correlation between function and change in PPT at the unaffected area, which indicates a potential central pain mechanism of SMT. Future studies should explore SMT effects using other experimental pain modalities, and greater dosing of SMT over a longer follow-up.

Introduction

Shoulder pain is one of the most common musculoskeletal pain complaints in general medical practice, with a prevalence ranging from 16-48%.^{13, 39} Treatment of shoulder pain with manual therapy techniques that include thoracic spinal manipulative therapy (SMT) is reported to produce positive clinical outcomes.^{2, 4, 11, 31, 44, 48} Manual therapy involves the use of hands on treatment by a healthcare provider to improve symptoms and function in patients with musculoskeletal dysfunction.^{22, 26, 37} For patients with shoulder pain, thoracic SMT has been theoretically used to improve spinal mobility deficits.^{45, 47} However, a more recent theoretical model suggests that SMT can modulate pain neurophysiologically at the peripheral and central nervous system.⁶

Randomized clinical trials in patients with shoulder pain have found superior outcomes when exercise or usual medical care was combined with manual therapy directed at the spine and shoulder^{2, 48} or the spine only⁴. Several single-arm trials have reported improved pain and disability after thoracic SMT as a stand-alone treatment for patients with shoulder pain.^{11, 31, 35, 44} Although clinical efficacy is reported with thoracic SMT for the treatment of shoulder pain, the mechanisms underlying the clinical improvements have not been well established. A recent study³⁵ found improvements in patient-rated outcomes of pain and function after a single bout of thoracic SMT in patients with subacromial pain syndrome, but did not find mechanical changes in thoracic spine or shoulder mobility. Neurophysiological mechanisms of pain modulation may explain the clinical benefits of thoracic SMT.

In patients with musculoskeletal pain, peripheral sensitization to pain occurs when nociceptors become more responsive to noxious stimulation or if afferent nerves develop increased excitability, resulting in hyperalgesia peripherally at the affected region.^{14, 23} Central

sensitization to pain is characterized by increased sensitivity to noxious stimuli due to changes in the processing of painful stimuli within the central nervous system.²³ Signs of central and peripheral^{1, 17, 38} pain sensitivity have been reported in patients with subacromial pain syndrome. Using pressure pain threshold (PPT) to measure pain sensitivity, studies^{1, 17} have reported peripheral sensitization based on increased sensitivity to pressure pain (reduced PPT) at the affected shoulder (acromion and deltoid) compared to the unaffected side. Central sensitization has also been reported in patients with subacromial pain syndrome based on increased sensitivity (via PPT) at regions remote to the painful shoulder.^{1, 17, 38} One of these studies¹⁷ reported that patients with subacromial pain syndrome showed signs of both peripheral and central sensitization based on increased sensitivity of the affected versus unaffected shoulder and signs of increased pain sensitivity overall compared to controls.

Pain relief after thoracic SMT may be due to neurophysiologic changes in pain sensitivity at the peripheral and /or central nervous system.⁶ Decreased sensitivity to pressure pain (increase in PPT) has been reported after SMT in patients with musculoskeletal pain.^{19, 21, 27, 28, 46} To date, no studies have characterized the neurophysiologic effects of pain sensitivity after thoracic SMT in patients with shoulder pain. If SMT effects are modulated by alterations in peripheral and/or central pain sensitivity, a clinical examination that identifies altered pain sensitivity may be helpful to guide the use of SMT. A purely a biomechanical basis for SMT may not be appropriate or adequate to guide treatment decision-making.

Subacromial impingement syndrome is a common diagnosis that can include various tissue pathologies, such as rotator cuff tendinopathy or tears, glenoid labral tear, subacromial bursitis, or biceps tendinopathy.^{12, 36} The term impingement indicates a mechanism of compression. However, there may be intrinsic mechanisms that result in pathologic changes in

subacromial structures, therefore just describing the location of pain may be most appropriate.⁴¹
^{12, 40} The term ‘subacromial pain syndrome’ defines shoulder pain located at the subacromial region, without identifying a mechanism.

The primary purpose of this study was to assess the effects of thoracic SMT on central and peripheral pain sensitivity measured with PPT in patients with subacromial pain syndrome compared to a sham thoracic SMT (Figure 1). The secondary purpose of this study was to examine the relationship between change in the mechanistic PPT measure and patient-rated outcomes of pain and function following thoracic SMT. It is hypothesized that patients receiving thoracic SMT compared to sham thoracic SMT will show: 1) increased PPT (decreased sensitivity to pressure pain) at the affected shoulder, indicating a decreased peripheral and/or central sensitivity to pain, 2) increased PPT at regions away from the affected shoulder (unaffected shoulder and over the lower trapezius muscle bilaterally) indicating decreased central sensitivity to pain, and 3) decreased pressure pain sensitivity will be related to improved patient-rated pain and function.

Methods

Participants

Participants (n=48) with subacromial pain syndrome were recruited from local physical and occupational therapy offices, physicians’ clinics, as well as by advertisement at a university gym. Three participants were excluded from the final analysis (all in the sham SMT group) because they had pain in both shoulders, leaving n=45 for final analysis. This study took place in a research laboratory in the Physical Therapy Department of Virginia Commonwealth University. Participants were recruited for 6 months, from November of 2012 to April of 2013. Inclusion criteria for patients with subacromial pain syndrome were: 1) pain for ≥ 6 weeks, 2)

pain $\geq 2/10$ on an 11-point numeric pain rating scale (NPRS), and 3) 18-60 years of age.

Subjects with shoulder pain also had to have 3 of the following 5 clinical signs of subacromial pain syndrome: 1) positive Hawkin's Test, 2) positive Neer Test, 3) pain during active elevation $> 60^\circ$ in the scapular or sagittal plane, 4) positive Jobe/Empty Can test for pain or weakness, 5) pain or weakness with resisted shoulder external rotation with the arm at the side.³⁰ Subjects were excluded from this study if they had 1) a history of shoulder, cervical spine, or thoracic spine surgery, 2) a primary complaint of neck or thoracic pain, 3) signs of central nervous system involvement, 4) signs of cervical nerve root involvement, 5) contraindications to manipulative therapy such as osteoporosis, metastatic disease, or systemic arthritis, 6) adhesive capsulitis, 7) instability of the shoulder, or 8) shoulder or arm pain with cervical rotation to the ipsilateral side, axial compression, or Spurling's Test.

Procedures

All participants were provided verbal and written explanation of study procedures and signed an informed consent approved by the Institutional Review Board of Virginia Commonwealth University. The participants completed an intake questionnaire (health screening questions, demographic information, and symptom history), a Fear Avoidance Beliefs Questionnaire (FABQ),³² a baseline numeric pain rating scale (NPRS) and a baseline Pennsylvania Shoulder Score (Penn).²⁵

The NPRS consisted of an 11-point scale ranging from 0 ("no pain at all") to 10 ("pain as bad as it can be"). The NPRS has shown to be reliable and responsive, with a minimal detectable change (MDC) of 2.5 points and a minimal clinically important difference (MCID) of 1.1 points.³³ The Penn is a patient-rated shoulder function/disability questionnaire that has been found to be reliable and responsive,²⁵ with scores range from 0-100 (100 = no pain or functional

loss). The MDC for the Penn is 12.1, and the MCID is 11.4 points.²⁵ Global rating of change (GROC) was assessed following treatment. The GROC is a 15-point scale ranging from -7 (a great deal worse), through 0 (no change), to +7 (a great deal better) and was given at the 24-48 hour follow-up to assess change in quality of life following treatment. GROC with an absolute value of 1-3 represent a small change, while change of 4-5 represents moderate change, and change of 6-7 represents large change.²⁴

Baseline PPT measurements at the bilateral deltoid and lower trapezius muscles were first taken. Participants were then randomly assigned to receive thoracic SMT or sham thoracic SMT treatment. Both the thoracic SMT and sham thoracic SMT treatments were administered by a licensed physical therapist (JK) with 11 years of orthopedic physical therapy experience. The SMT interventions were applied to the lower thoracic spine, mid thoracic spine, and upper thoracic spine (cervicothoracic junction). Immediately following the treatment, PPT measures and the NPRS were administered again. At 24-48 hours after treatment, participants completed another NPRS and Penn, as well as the GROC. Figure 2 depicts the experimental procedures.

Randomization and Blinding

A randomization list for treatment group assignments of the participants was computer generated with random blocking using nQuery Advisor software (Statistical Solutions, Saugus, MA). A lab assistant placed the treatment assignments into sequentially numbered privacy envelopes to conceal treatment group allocation. Participants were blinded to treatment assignment, and were told prior to the start of testing they would receive an active or a placebo treatment. Patients assigned to the thoracic SMT group were told that they were receiving “spinal manipulative therapy” while those assigned to the sham thoracic SMT group were told they would receive a “therapist-assisted range of motion” treatment. An investigator blinded to

treatment (non-treating investigator) took all PPT measurements. This non-treating investigator was not in the room during treatment, and participants were asked to not discuss their treatment with the non-treating investigator. Blinding was assessed after treatment by asking the patient if they believed they received an active or placebo (a look-alike treatment) treatment.

Thoracic Manipulation and Sham Manipulation

The SMT interventions were applied to the lower thoracic spine, mid thoracic spine, and cervicothoracic junction. Each technique was applied 2 times, for a total of 6 thoracic SMT or sham thoracic SMT maneuvers. The thoracic SMT techniques have previously been used in clinical trials investigating the effects and outcomes of thoracic SMT in patients with shoulder pain (Figure 3),^{11, 31, 44} and the sham SMT was previously validated as a believable active treatment.²⁹ During administration of the thoracic SMT, a high velocity, low-amplitude thrust was applied at the end of available spinal motion as the patient exhaled. For the mid and lower thoracic SMT, the participants were prone, and the thrust was directed in the posterior to anterior direction. For the cervicothoracic junction SMT, participants were seated, and the thrust was an axial (cephalad) distraction. The sham SMT was performed with identical body positioning of both the subject and therapist. During the sham SMT, the therapist maintained manual contact through the range of motion during exhalation, but no manipulative thrust was delivered.

Pressure Pain Threshold Measurements

Cutaneous sensation using a 10g monofilament was tested at each of the PPT test sites to ensure patients had protective sensation. After monofilament testing, baseline PPT measurements were taken from the participants. PPT was measured using a mechanical pressure algometer (Wagner Instruments, Greenwich, CT) with a flat rubber covered 1 cm² round force gauge (Figure 4). PPT was measured bilaterally (affected and unaffected sides) over the middle

deltoid and the lower trapezius muscle belly (between the spine and scapula at a spinal level between T5 and T7). PPT measures at the affected shoulder were used to examine changes in peripheral and/or central pain sensitivity, while PPT at the unaffected shoulder and over the bilateral lower trapezius muscle were used to define changes in central pain sensitivity (Figure 1). The participant was instructed to say “pain” when the pressure applied through the algometer changed from a sensation of pressure to that of pain, and the pressure reading was recorded from the algometer. The order of PPT measurements at each location was randomized, and each site was tested 3 times. Measurements were taken at every site in the randomized order, and the cycle was repeated until 3 measurements from each site were obtained. There was approximately 1 minute between repetitions at each site. The average of the final 2 readings at each location was used for data analysis. Test re-test reliability and error values were calculated using these methods on 10 healthy volunteers. The intraclass correlation coefficient ($ICC_{(3,1)}$) values were excellent, at 0.98 and 0.93 for the deltoid and the lower trapezius, respectively. The standard error of the measure (SEM) was 0.24 kg/cm^2 at the deltoid and 0.50 kg/cm^2 at the lower trapezius, while the MDC was 0.34 kg/cm^2 at the deltoid and 0.71 kg/cm^2 at the lower trapezius.

A sample size calculation was based on the primary aim, using a 2 x 2 ANOVA comparing the changes between the groups with 80% power and a significance level of $\alpha=0.05$. The sample size was calculated from pilot data examining the change in PPT pre- to post-treatment in a sample of 6 individuals with subacromial pain syndrome. The preliminary data showed a pre- to post-treatment effect size of 0.83 for PPT at the deltoid, and an effect size of 0.87 at the lower trapezius. The sample size required for these effect sizes were $n=24$ subjects per group for the deltoid measure and $n=22$ per group for the lower trapezius PPT measure. Therefore, a sample size of 24 subjects per group for a total of $n=48$ was required for the study.

Data Analysis

All statistical analyses were performed using JMP Pro 10.0.0 software (SAS Institute, Cary, NC) with level of significance set at $\alpha=0.05$. PPT results were compared using a 2 x 2 mixed model ANCOVA, with gender used as a covariate, as the magnitude of PPT has been shown to vary by gender.^{8, 15, 16, 28} NPRS results were compared using a 2 x 3 mixed-model ANOVA using the factors of treatment group (thoracic SMT and sham thoracic SMT) and time (pre-treatment, post-treatment, and 24-48 hour follow-up). Penn scores were compared using a 2 x 2 mixed-model ANOVA using the factors of treatment group and time (pre-treatment and 24-48 hour follow-up). A t-test was used to compare GROC scores between the groups at the 24-48 hour follow-up. Correlations were calculated between the pre- to post-treatment change in PPT and patient rated outcome variables to assess the relationships within the study sample as a whole and within the thoracic SMT treatment group separately. A Bonferroni corrected $\alpha=0.013$ ($0.05/4$) was used for correlations, as the relationship between PPT and each outcome variable was assessed at the 4 PPT test locations. A two-sample test of proportions was used to compare the proportion of participants in each group who believed they received an active or placebo treatment.

Results

Forty-five (n=45) individuals with unilateral shoulder pain were randomly assigned to receive thoracic SMT (n=24) or sham thoracic SMT (n=21). Participant characteristics are available in Table 1. Table 2 and Figures 5 and 7 show the results of the PPT measurements. Patient-rated outcomes are shown in Table 3 and Figures 6 and 8. The mixed-model ANCOVA results for PPT comparisons reported in Table 4 indicates there were no Group x Time interactions ($p \geq 0.580$), nor were there any main effects for Group or Time ($p \geq 0.337$). There

were no Group x Time interactions for patient-rated outcomes of pain (NPRS) or function (Penn), with p-values ≥ 0.278 . There was a main effect for Time for the NPRS and the Penn ($p < 0.001$), indicating that scores improved in both groups over time (Table 5). NPRS decreased across the groups 1.1, 95% CI [0.6, 1.6] points from pre-treatment to post-treatment measures (SMT group = 0.8, 95% CI [0.1, 1.6] and sham group = 1.4, 95% CI [0.6, 2.2]) and 1.5 [95% CI = 0.9, 2.0] points from pre-treatment to the 24-48 hour follow-up (SMT group = 1.0, 95% CI [0.3, 1.8] and sham group = 1.9, 95% CI [1.1, 2.7]). Penn scores improved across the groups 10.1, 95% CI [7.3, 12.9] points from pre-treatment to 24-48 hour follow-up (SMT group = 9.2, 95% CI [5.4, 13.0] and sham group = 11.0, 95% CI [6.9, 15.0]). A t-test revealed no statistically significant difference in the GROC between the two treatment groups, ($t_{(43)}=1.2$, $p=0.235$). The two-sample test for proportions was not significant ($p=0.312$) indicating no difference between the groups for participants who felt they received an active form of treatment; 76% of participants in the thoracic SMT group and 62% of patients within the sham SMT group responded that they received the active form of treatment.

Correlations between the pre- to post-treatment change in PPT and patient rated outcome variables (NPRS, Penn, GROC) were calculated within the entire study sample and in the thoracic SMT group alone. Relationships were assessed between the change in PPT at each location and baseline NPRS and Penn scores, as well as the change in NPRS and Penn. The only significant correlation was for the thoracic SMT group, with a moderate correlation (0.52, $p=0.009$) between change in PPT at the unaffected lower trapezius and baseline Penn. There were no other significant relationships between change in PPT and the patient-rated outcomes of baseline pain or Penn, pre- to post-treatment change in pain or Penn, or GROC for the entire study sample or the SMT group.

Exploratory subgroup analyses were performed post hoc to examine the effects of age, baseline pain, baseline Penn score, BMI, duration of symptoms, and gender on patient-rated outcomes. Each of these variables was added individually into mixed model ANOVA to assess their effects on pain, Penn score, and GROC. There were no significant interactions of any of these variables with Group and Time. BMI had a main effect on GROC ($p = 0.035$), with participants with BMI < 30 ($n=11$) having a GROC of 2.0 ± 2.3 points and those with BMI ≥ 30 ($n=34$) showing a GROC of 0.5 ± 2.0 point. This means that patients with lower BMI may report greater improvement in symptoms, with this change of 2 points representing only minimal change.

There were main effects for gender, BMI, and baseline Penn score ($p \leq 0.012$) on pain. Males had less baseline pain (3.4 ± 1.4 points) than females (4.0 ± 1.5 points). Males ($n=22$) also showed greater pain reduction immediately following treatment (1.6 ± 1.82 points) and maintained the effect at 24 hours, whereas females ($n=23$) had a decline in pain from pre- to post-treatment of $0.6 (\pm 2.34)$ points, with a decrease of $1.4 (\pm 1.87)$ points 24-48 hours after treatment. Participants with a BMI < 30 had a decrease of $1.4 (\pm 1.7)$ points pre- to post-treatment and $1.7 (\pm 1.7)$ points 24-48 hours after treatment, whereas participants with BMI ≥ 30 showed a decrease of $0.3 (\pm 2.0)$ points immediately following treatment and $0.9 (\pm 2.0)$ after 24-48 hours, indicating that patients with lower BMI may have a greater response to SMT. Participants with BMI of 30 or greater comprised less than 25% (11 of 45) of study participants, so this is not a balanced comparison with regard to proportion of participants within the study. Participants with baseline Penn scores ≤ 75 in both groups had higher pain scores (3.3 ± 1.3) across all time points than those with Penn scores > 75 (2.3 ± 1.3). This may also be due in part

to the fact that the Penn has 30/100 points for pain, so those with greater pain would inherently have lower Penn scores. A mixed model ANOVA performed using only the Penn function score (pain scores removed) found no significant interactions or main effects ($p > 0.215$).

The subgroup analyses for Penn scores showed a main effect for gender and baseline pain. Females had lower baseline Penn scores (65.5 ± 9.6 points) than males (78.0 ± 9.4 points), but both genders showed similar improvements in Penn 24-48 hours after treatment. However, the improvement for females was clinically meaningful (11.4 ± 9.6 points), while the improvement for males was not (9.5 ± 9.4 points). Participants with $> 4/10$ baseline pain showed clinically meaningful improvement in Penn (11.5 ± 9.3 points), whereas those with $\leq 4/10$ baseline pain had less improvement (7.9 ± 9.6 points). This may indicate that participants with greater baseline pain may show greater functional improvements following treatment with SMT.

A 2 x 2 ANCOVA was performed to examine pre- to post-treatment change in PPT measures between individuals who showed a clinically meaningful reduction of ≥ 2 points in pain ($n=18$) to those who showed a change < 2 points ($n=27$). There were no interaction effects for Group and Time ($p \geq 0.07$), nor were there any main effects for Group or Time ($p \geq 0.240$). Those individuals who showed a reduction in pain ≥ 2 points were analyzed according to treatment group (SMT or sham) to assess for differences in any PPT measure following treatment. The 2 x 2 ANCOVA within this subset revealed no significant differences between the thoracic SMT ($n=8$) and sham thoracic SMT ($n=10$) groups; no interaction effects of Group and Time ($p \geq 0.132$) and no main effects for Group or Time on PPT ($p \geq 0.083$).

A 2 x 2 ANCOVA was performed to examine changes in PPT in individuals who showed a clinically meaningful improvement ≥ 11.4 points in Penn scores ($n=15$) to those who showed a

change of < 11.4 points ($n=30$). There were no interactions of Group and Time at any of the PPT locations ($p \geq 0.189$), nor were there any main effects for Group or Time ($p \geq 0.185$). A 2×2 ANCOVA was also performed examining the effects of each treatment (SMT or sham) on PPT for those who experienced ≥ 11.4 points improvement in Penn score (SMT $n=6$, sham SMT $n=9$). There were no Group \times Time interactions ($p \geq 0.119$) or any main effects for Group or Time ($p \geq 0.147$).

Discussion

Thoracic SMT did not have any greater effect than the sham SMT on measures indicative of peripheral or central pain sensitivity or patient-rated outcomes. Both groups had improved patient rated outcomes, but the SMT group did not show greater improvement over the sham SMT group. Clinical improvements were found irrespective of whether patients received thoracic SMT or the sham SMT. However, when we examined the relationship between mechanism (PPT) and outcome in the thoracic SMT group, a higher level of function (higher Penn score) at baseline was related to increased pain threshold at an unaffected region (the lower trapezius) following treatment. This may suggest a neurophysiologic mechanism of action at the central nervous system for thoracic SMT in patients with a higher level of baseline shoulder function. However, this was the only significant correlation of patient-rated outcomes with PPT mechanistic measures, limiting the implications of this finding.

Changes in patient-rated outcomes indicated small, but potentially meaningful, improvements. Pain scores across both groups decreased 1.1 points from pre- to post-treatment, and decreased 1.5 points between pre-treatment ratings and ratings 24-48 hours following treatment. This change in pain represents clinically meaningful change as it meets or exceeds the MCID of 1.1 point for the NPRS³³ for individuals with shoulder pain. There were 8 (33.3%)

participants in the SMT group and 10 (47.6%) in the sham SMT group that had a reduction in pain greater than the MCID. The mean improvement of 10.0 points in Penn score falls slightly short of the MCID of 11.4²⁵. There were 6 (25%) participants in the SMT group and 9 (42.9%) participants in the sham SMT group with a change in Penn score greater than the MCID. Since there were no differences noted between treatment groups for patient-rated outcomes, this suggests that the manipulative thrust delivered at the thoracic spine may not be the component of the manual therapy intervention that leads improvements in pain or function. The fact that both groups were similar in perception that they received an active form of treatment indicates they were adequately blinded and knowledge of treatment group did not have an effect on outcomes or mechanistic measures between groups.^{3, 7, 10}

Prior studies^{9, 28} of SMT have measured PPT at the region of treatment application and at remote regions. In patients with neck pain, Martinez-Segura et al.²⁸ reported a similar, albeit small, immediate increase in PPT at the neck and at remote regions (elbow and leg) following cervical and thoracic SMT. These changes in PPT local and distal to the painful region indicate that SMT may have an effect on central and/or peripheral pain sensitivity. However, the changes in PPT did not meet the minimal detectable change and assessor bias could have been a factor as the evaluator knew that all participants (both groups) received an active treatment (cervical SMT or thoracic SMT).²⁸ A strength of our study is that our blinded assessor did not know treatment group assignments. In a study of asymptomatic participants, those who received thoracic SMT⁹ had no changes in PPT measured at the hand and the foot as compared to those receiving cervical exercise or quiet rest. These results may have limited comparison value to our study, as we applied SMT to a group of individuals with shoulder pain who may have had altered pain sensitivity prior to delivery of SMT.

The location of SMT may affect the impact on central and peripheral pain sensitivity. Cervical SMT has lead to increased PPT locally at the cervical region,^{19, 46} head,²⁷ and shoulders in patients with cervical pain.¹⁹ The change in PPT at the cervical region could be due to changes in central or peripheral pain intensity, however, the changes at the head (trigeminal nerve distribution) and shoulders would seem to indicate a central mechanism in pain modulation. Cervical SMT has also shown to increase PPT over both lateral epicondyles in patients with unilateral lateral epicondylagia.²¹ This bilateral effect could indicate a reduction in central pain sensitivity at this cervical innervated region. Two clinical trials examining PPT in patients with low back pain immediately following lumbar SMT^{18, 20} and thoracic SMT²⁰ failed to show changes in PPT at the lumbosacral regions. Therefore, thoracic and lumbar SMT may not have the same mechanisms of action as cervical SMT. However, our study showed limited support for a potential affect on immediate changes in central pain sensitivity with thoracic SMT, as higher baseline shoulder function (Penn) had a moderate positive relationship with reduced pain sensitivity at a region remote from the painful shoulder. The correlation ($r=0.52$) indicates that 27% of the change in PPT at the unaffected lower trapezius muscle was accounted for by baseline Penn score.

Other experimental measures of pain sensitivity may provide different results, as different experimental pain modalities may selectively facilitate various nociceptors and collaborative pathways that may be affected by SMT. Temporal summation (central pain sensitivity)⁴³ from heat-induced pain was reduced to a greater degree with SMT as compared to either a cervical exercise or rest group, despite a lack of differences noted with PPT measures.⁹ Mohammadian et al.³⁴ reported greater reductions in allodynia and hyperalgesia at a region of capsaicin-induced (chemically induced) inflammation at the forearm following thoracic SMT compared to placebo

SMT, but it is unclear if these findings indicate changes in peripheral and/or central pain sensitivity because participants were tested only unilaterally at the region of pain.

Both the sham SMT and the thoracic SMT groups in this study showed improvement in patient-rated outcomes, which suggests an alternative hypotheses that the mechanism of SMT is related to factors of manual contact, positioning of the subject and moving them through the range of motion, interaction with a healthcare provider, or placebo effects. The mechanisms of improvement from manual therapy to the thoracic spine may be independent of the use of a manipulative thrust. Since only immediate effects were assessed in this study, it is also possible that greater benefits and mechanistic changes with SMT would be seen with multiple treatments or over a greater time period following treatment. Prior clinical trials using thoracic SMT and/or mobilization as part of a manual therapy regimen in the treatment of shoulder pain have reported positive effects compared to exercise^{2, 48} and usual medical care without the use of manual therapy.⁴ These studies used multiple treatments with manual therapy over weeks, rather than the single treatment and assessment of immediate effects performed in our study.

Single-arm clinical trials examining short-term effects of thoracic SMT as a stand-alone treatment for shoulder pain have reported positive effects in patient-rated outcomes, but it is difficult to draw cause and effect conclusions from these studies due to the lack of a comparator treatment or control group.^{11, 31, 35, 44} The improvements we found in patient-rated pain are similar in magnitude to the results of Boyles et al. (1.1 - 1.2 point improvement of pain elicited during impingement signs), and Muth et al. (1.1 - 2.8 point improvements with arm elevation and impingement signs), but our results did not reach the magnitude of the pain reduction reported by Strunce et al. (31.9 mm improvement on visual analog scale).^{11, 35, 44} The improvements in Penn score in our study were similar to those reported by Muth et al. in their single-arm trial

examining the effects of thoracic SMT.³⁵ Although the Penn score results were significant, both studies failed to reach the threshold for clinically meaningful difference in Penn.²⁵ Interestingly, Muth et al. reported that 80% participants had clinically meaningful reductions in pain, but only 33% had clinically meaningful improvements in function (Penn). Of our participants, 40% had meaningful reductions in pain and 33% had meaningful improvements in Penn scores across groups. Our results and the results of these previous studies assessed immediate or short-term (2-10 days) effects, and further improvements in function may not have yet been realized.

The improvement we found in GROC scores was similar to that reported by Boyles et al., indicating a small improvement, but smaller than Strunce et al. who reported a moderate improvement.^{11, 44 24} Strunce et al. used a pragmatic approach in applying thoracic SMT based on joint restrictions noted during examination, whereas our study and that of Boyles et al. used a standardized treatment approach. It is possible that the use of a pragmatic approach could improve outcomes, especially if the therapist engaged the patient with the treatment rationale and leveraged expectations prior to the application of particular techniques.³

It has been suggested that the structured experience of patient-clinician physical interaction during manual therapy may have an effect beyond the treatment technique that leads to some of the changes reported with manual therapy.⁵ The improvements in both the SMT group and the sham SMT group in patient-rated outcomes, coupled with the lack of difference in PPT measures may be explained by this type of interaction. The majority of participants in both groups felt that they received an active form of treatment. However, without a non-treatment group to represent natural history of this condition, it is unclear if there was a placebo effect.

The baseline PPT measurements at the deltoid in participants with subacromial pain syndrome within our study were similar in magnitude to those reported by Paul et al.³⁸ and

Camargo et al.¹⁹ Our results also fall within the range of 3.09-5.45 kg/cm² that was reported by Coronado et al.¹⁶ for the average of 3 locations around the shoulder (supraspinatus, infraspinatus, acromion) for males and females at the affected and unaffected shoulder. The participants with subacromial pain syndrome in our study had mean PPT of 3.68 kg/cm² at the deltoid and 4.40 kg/cm² at the lower trapezius compared to 4.28 (\pm 1.57) kg/cm² at the deltoid and 5.52 (\pm 1.83) kg/cm² at the lower trapezius we saw in a pilot sample of 10 healthy volunteers. Although the values for our participants with shoulder pain would indicate a greater sensitivity to pain than our small sample of healthy volunteers, no conclusions can be drawn regarding peripheral or central sensitization to pain through our study design.

Limitations

Pressure is a nonspecific stimulus that triggers mechanoreceptors and nociceptors in the skin and underlying tissues.⁴² It also does not allow for the noxious stimulus to be delivered rapidly and briefly, as it is applied gradually until the pain threshold is reached. Other pain eliciting modalities such as electrical, thermal, or chemical stimulation may produce different results when assessing SMT by providing variable stimuli to nociceptors and respective pathways and induce pain by means other than mechanoreception (e.g. chemical or thermal induced).⁴² Temporal summation (via multiple consecutive heat impulses at the hand and foot) has been used as a proxy measure of dorsal horn excitability and demonstrated changes following thoracic SMT.⁹ Spatial summation techniques (noxious stimulus of a fixed intensity applied at multiple sites simultaneously to magnify response) could also be used to assess central nervous system response to noxious stimuli.⁴² Our study included only a single session (dose) of thoracic SMT. Characterizing mechanisms and outcomes following multiple doses would more closely mirror clinical practice and may yield different results. We also measured PPT

immediately following application of treatment, whereas our final pain and Penn scores were collected at 24-48 hours following treatment, so it is unclear how PPT related to outcomes 1-2 days following treatment. Since only 4 patients in each group (8 out of the sample of 45) were actively undergoing care, it is possible that participants do not reflect those seen at rehabilitation clinics. We also did not assess subjects enrolling into this study for peripheral or central sensitization to pain, and prior research¹⁷ suggests that there may be a heterogeneous mix of patients with shoulder pain exhibiting peripheral and/or central pain sensitization.

Since pain is an effect from peripheral nociceptive stimulation (from multiple potential stimuli) and processing mechanisms at multiple central nervous system structures, future studies should consider using alternate experimental pain modalities or multiple experimental pain modalities to characterize pain sensitivity following treatment. It would also be of benefit to measure mechanistic pain responses over longer duration treatment studies. This would assess potential reductions in peripheral and/or central pain sensitivity along a course of treatment that more closely resembles the multiple visit treatment regimens patients experience when treated clinically with manual therapy, particularly in conjunction with rehabilitation exercise. Future studies examining pain sensitivity in patients at a specific point in their care cycle (i.e. at initial visit to primary care provider or initially upon entry into rehabilitation) may also help to determine the point in care when thoracic SMT may be of greatest benefit.

Although our initial power analysis indicated that 48 participants were required for this study, we assessed 45. Our pre- to post-treatment measurements within each group and the difference in pre- to post-treatment measurements between the groups was much less than the measurement error of 0.34 kg/cm² for the deltoid and 0.71 kg/cm² for the lower trapezius.

Therefore, the addition of 3 more subjects to the sham SMT group likely would not have lead to a change in our overall results.

Conclusions

Thoracic SMT did not alter peripheral or central sensitivity to pressure pain compared to sham SMT. There was also no difference in patient-rated outcomes between the groups.

Interestingly, both groups had improved patient rated outcomes following treatment, but there were no changes in PPT in either group. Since a moderate positive correlation was seen between shoulder function (Penn) and change in PPT at a location remote to painful shoulder in the SMT group, this could indicate a central mechanism for pain modulation from thoracic SMT in patients with greater shoulder function. Clinically, thoracic SMT leads to improvements in pain and function in patients with shoulder pain, but since effects were similar to sham SMT they may be related to factors such as manual contact, positioning of the subject and moving them through spinal range of motion, interaction with a healthcare provider, or placebo effect.

References

1. Albuquerque-Sendin F, Camargo PR, Vieira A, Salvini TF. Bilateral myofascial trigger points and pressure pain thresholds in the shoulder muscles in patients with unilateral shoulder impingement syndrome: a blinded, controlled study. *Clin J Pain*. 2013;29:478-486.
2. 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.
3. Benz LN, Flynn TW. Placebo, nocebo, and expectations: leveraging positive outcomes. *J Orthop Sports Phys Ther*. 2013;43:439-441.
4. 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.
5. Bialosky JE, Bishop MD, George SZ, Robinson ME. Placebo response to manual therapy: something out of nothing? *J Man Manip Ther*. 2011;19:11-19.
6. 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.
7. Bialosky JE, Bishop MD, Robinson ME, Barabas JA, George SZ. The influence of expectation on spinal manipulation induced hypoalgesia: an experimental study in normal subjects. *BMC Musculoskelet Disord*. 2008;9:19, DOI 10.1186/1471-2474-9-19.

8. Binderup AT, Arendt-Nielsen L, Madeleine P. Pressure pain sensitivity maps of the neck-shoulder and the low back regions in men and women. *BMC Musculoskelet Disord*. 2010;11:234, DOI 10.1186/1471-2474-11-234.
9. Bishop MD, Beneciuk JM, George SZ. Immediate reduction in temporal sensory summation after thoracic spinal manipulation. *Spine J*. 2011;11:440-446.
10. Bishop MD, Mintken PE, Bialosky JE, Cleland JA. Patient expectations of benefit from interventions for neck pain and resulting influence on outcomes. *J Orthop Sports Phys Ther*. 2013;43:457-465.
11. 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.
12. Braman JP, Zhao KD, Lawrence RL, Harrison AK, Ludewig PM. Shoulder impingement revisited: evolution of diagnostic understanding in orthopedic surgery and physical therapy. *Med Biol Eng Comput*. 2013; DOI 10.1007/s11517-013-1074-1
13. Broadhurst NA, Barton CA, Yelland LN, Martin DK, Beilby JJ. Managing shoulder pain in general practice--the value of academic detailing. *Aust Fam Physician*. 2006;35:751-752.
14. Chaban VV. Peripheral sensitization of sensory neurons. *Ethn Dis*. 2010;20:S1-3-6.
15. Chesterton LS, Barlas P, Foster NE, Baxter GD, Wright CC. Gender differences in pressure pain threshold in healthy humans. *Pain*. 2003;101:259-266.
16. Coronado RA, Kindler LL, Valencia C, George SZ. Thermal and pressure pain sensitivity in patients with unilateral shoulder pain: comparison of involved and uninvolved sides. *J Orthop Sports Phys Ther*. 2011;41:165-173.

17. Coronado RA, Simon CB, Valencia C, George SZ. Experimental Pain Responses Support Peripheral and Central Sensitization in Patients With Unilateral Shoulder Pain. *Clin J Pain*. 2013; [Epub ahead of print]
18. Cote P, Mior SA, Vernon H. The short-term effect of a spinal manipulation on pain/pressure threshold in patients with chronic mechanical low back pain. *J Manipulative Physiol Ther*. 1994;17:364-368.
19. de Camargo VM, Albuquerque-Sendin F, Berzin F, Stefanelli VC, de Souza DP, Fernandez-de-las-Penas C. Immediate effects on electromyographic activity and pressure pain thresholds after a cervical manipulation in mechanical neck pain: a randomized controlled trial. *J Manipulative Physiol Ther*. 2011;34:211-220.
20. de Oliveira RF, Liebano RE, Costa Lda C, Rissato LL, Costa LO. Immediate effects of region-specific and non-region-specific spinal manipulative therapy in patients with chronic low back pain: a randomized controlled trial. *Phys Ther*. 2013;93:748-756.
21. Fernandez-Carnero J, Fernandez-de-las-Penas C, Cleland JA. Immediate hypoalgesic and motor effects after a single cervical spine manipulation in subjects with lateral epicondylalgia. *J Manipulative Physiol Ther*. 2008;31:675-681.
22. Greenman PE. *Principles of manual medicine*. 2nd. Baltimore: Williams & Wilkins; 1996;75-91.
23. Haines DE. *Fundamental neuroscience*. 3rd. Philadelphia: Churchill Livingstone; 2006;280-301.
24. Jaeschke R, Singer J, Guyatt GH. Measurement of health status. Ascertaining the minimal clinically important difference. *Control Clin Trials*. 1989;10:407-415.

25. 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.
26. Maitland GD. *Maitland's Vertebral Manipulation*. 7th. New York: Elsevier; 2005;1-15.
27. Mansilla-Ferragut P, Fernandez-de-Las Penas C, Albuquerque-Sendin F, Cleland JA, Bosca-Gandia JJ. Immediate effects of atlanto-occipital joint manipulation on active mouth opening and pressure pain sensitivity in women with mechanical neck pain. *J Manipulative Physiol Ther*. 2009;32:101-106.
28. Martinez-Segura R, De-la-Llave-Rincon AI, Ortega-Santiago R, Cleland JA, Fernandez-de-Las-Penas C. Immediate changes in widespread pressure pain sensitivity, neck pain, and cervical range of motion after cervical or thoracic thrust manipulation in patients with bilateral chronic mechanical neck pain: a randomized clinical trial. *J Orthop Sports Phys Ther*. 2012;42:806-814.
29. Michener LA, Kardouni JR, Lopes Albers AD, Ely JM. Development of a sham comparator for thoracic spinal manipulative therapy for use with shoulder disorders. *Man Ther*. 2013;18:60-64.
30. Michener LA, Walsworth MK, Doukas WC, Murphy KP. Reliability and diagnostic accuracy of 5 physical examination tests and combination of tests for subacromial impingement. *Arch Phys Med Rehabil*. 2009;90:1898-1903.
31. Mintken PE, Cleland JA, Carpenter KJ, Bieniek ML, Keirns M, Whitman JM. Some factors predict successful short-term outcomes in individuals with shoulder pain receiving cervicothoracic manipulation: a single-arm trial. *Phys Ther*. 2010;90:26-42.

32. Mintken PE, Cleland JA, Whitman JM, George SZ. Psychometric properties of the Fear-Avoidance Beliefs Questionnaire and Tampa Scale of Kinesiophobia in patients with shoulder pain. *Arch Phys Med Rehabil*. 2010;91:1128-1136.
33. 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.
34. Mohammadian P, Gonsalves A, Tsai C, Hummel T, Carpenter T. Areas of capsaicin-induced secondary hyperalgesia and allodynia are reduced by a single chiropractic adjustment: a preliminary study. *J Manipulative Physiol Ther*. 2004;27:381-387.
35. Muth S, Barbe MF, Lauer R, McClure PW. The effects of thoracic spine manipulation in subjects with signs of rotator cuff tendinopathy. *J Orthop Sports Phys Ther*. 2012;42:1005-1016.
36. Papadonikolakis A, McKenna M, Warne W, Martin BI, Matsen FA, 3rd. Published evidence relevant to the diagnosis of impingement syndrome of the shoulder. *J Bone Joint Surg Am*. 2011;93:1827-1832.
37. Paris SV. A history of manipulative therapy through the ages and up to the current controversy in the United States. *Journal of Manual and Manipulative Therapy*. 2000;8:66-77.
38. Paul TM, Soo Hoo J, Chae J, Wilson RD. Central hypersensitivity in patients with subacromial impingement syndrome. *Arch Phys Med Rehabil*. 2012;93:2206-2209.
39. Pope DP, Croft PR, Pritchard CM, Silman AJ, Macfarlane GJ. Occupational factors related to shoulder pain and disability. *Occup Environ Med*. 1997;54:316-321.

40. Schellingerhout JM, Verhagen AP, Thomas S, Koes BW. Lack of uniformity in diagnostic labeling of shoulder pain: time for a different approach. *Man Ther*. 2008;13:478-483.
41. Seitz AL, McClure PW, Finucane S, Boardman ND, 3rd, Michener LA. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? *Clin Biomech (Bristol, Avon)*. 2011;26:1-12.
42. Staahl C, Drewes AM. Experimental human pain models: a review of standardised methods for preclinical testing of analgesics. *Basic Clin Pharmacol Toxicol*. 2004;95:97-111.
43. Staud R, Craggs JG, Robinson ME, Perlstein WM, Price DD. Brain activity related to temporal summation of C-fiber evoked pain. *Pain*. 2007;129:130-142.
44. 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.
45. Sueki DG, Chaconas EJ. The effect of thoracic manipulation on shoulder pain: a regional interdependence model. *Phys Ther Rev*. 2011;16:399-408.
46. Vernon HT, Aker P, Burns S, Viljakaanen S, Short L. Pressure pain threshold evaluation of the effect of spinal manipulation in the treatment of chronic neck pain: a pilot study. *J Manipulative Physiol Ther*. 1990;13:13-16.
47. Wainner RS, Whitman JM, Cleland JA, Flynn TW. Regional interdependence: a musculoskeletal examination model whose time has come. *J Orthop Sports Phys Ther*. 2007;37:658-660.

48. 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.

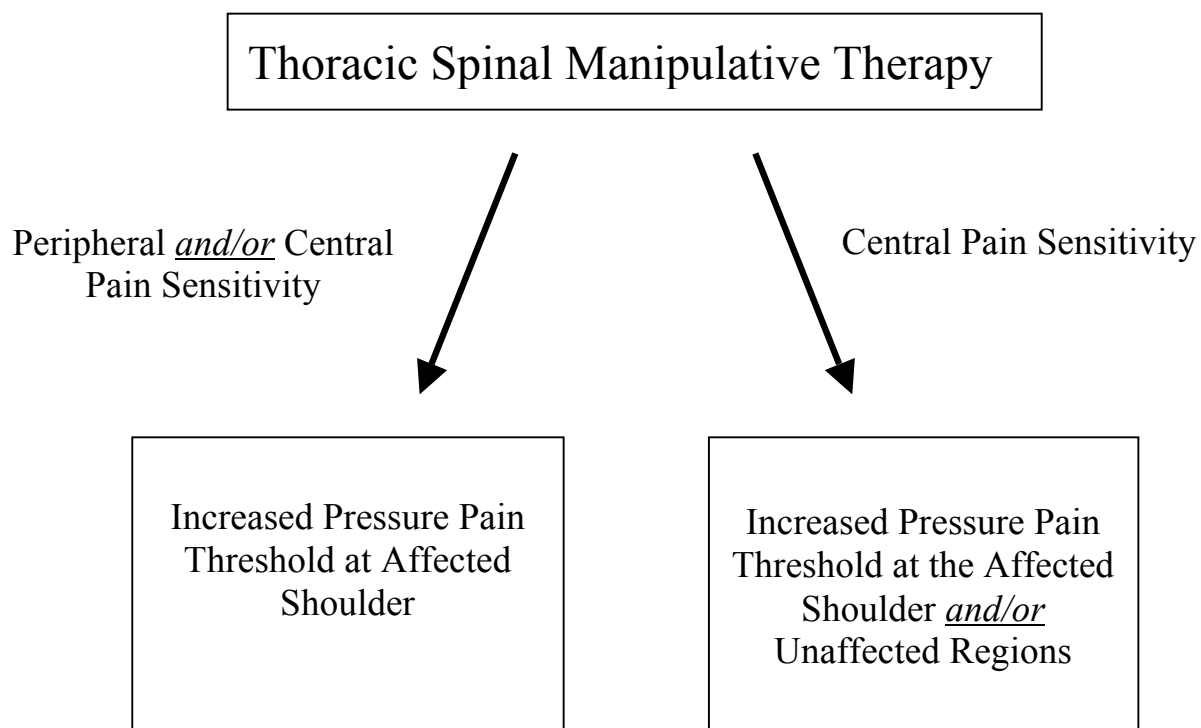


Figure 1. Theoretical framework for change in pain sensitivity following thoracic spinal manipulative therapy (SMT).

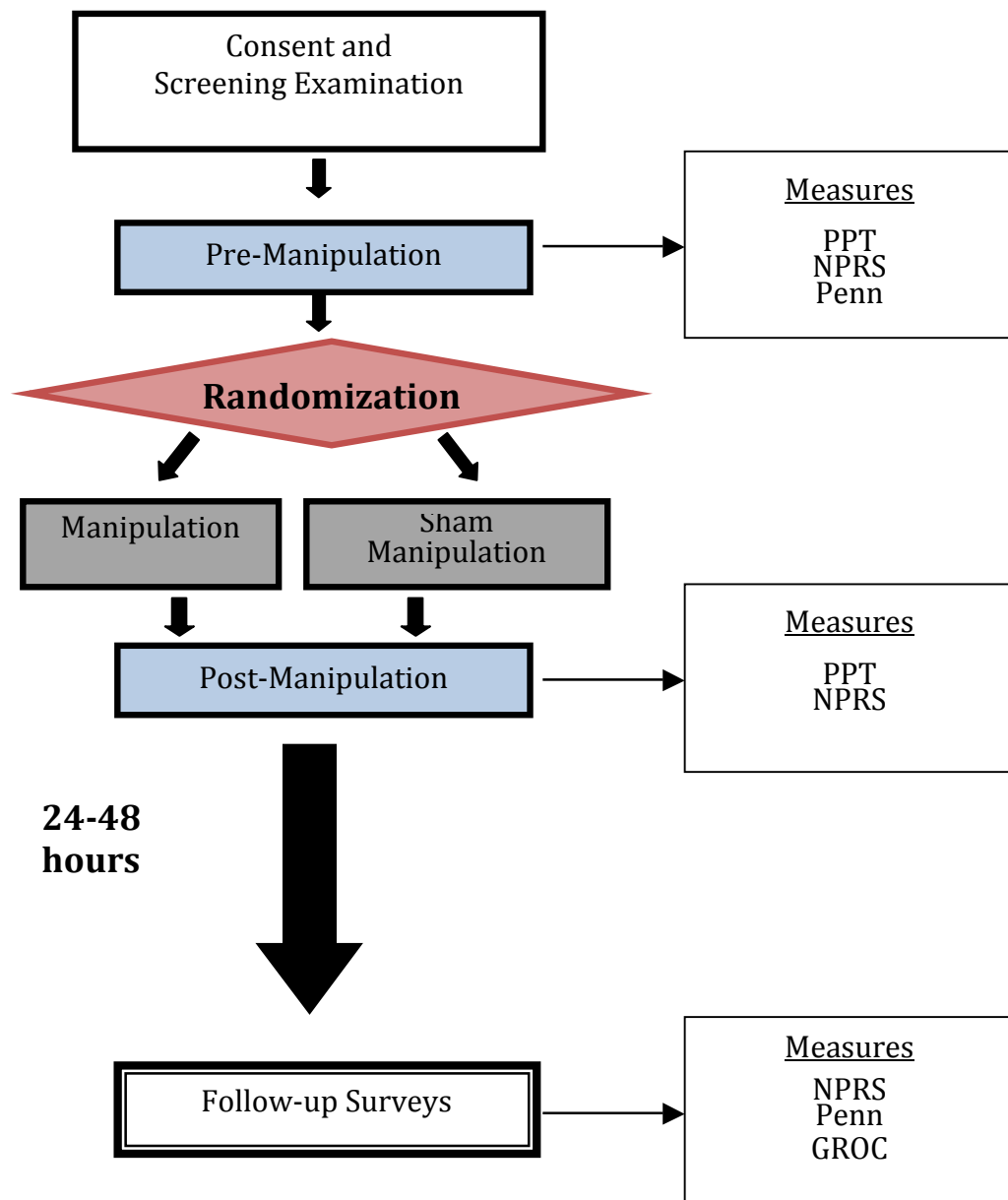
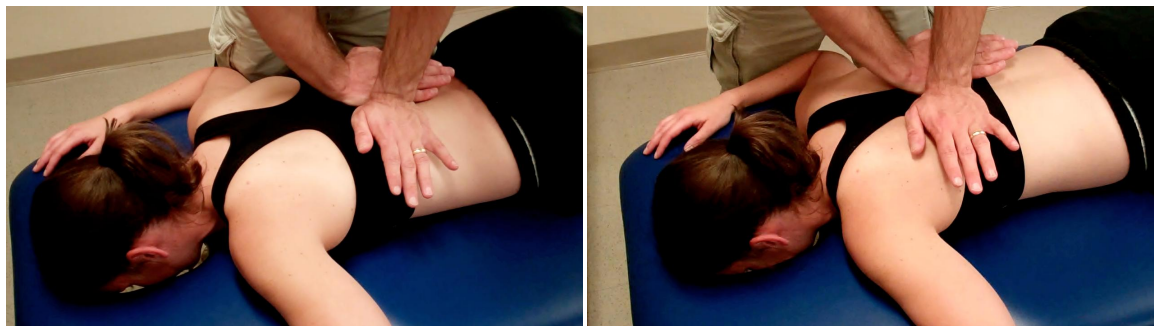
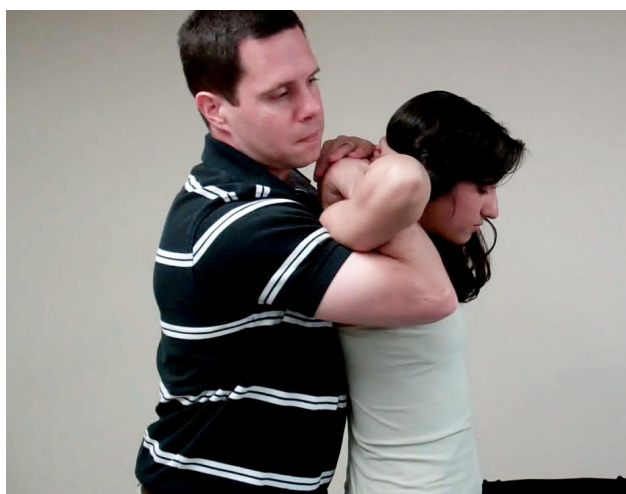


Figure 2. Flow diagram for experimental procedures. Abbreviations: PPT= Pressure Pain Threshold, NPRS = numeric pain rating scale, Penn = Penn Shoulder Scale, GROC = global rating of change



The mid and lower thoracic manipulation techniques are performed with the patient lying prone. The therapist positions the hypothenar eminence of his hands over the transverse processes of the thoracic vertebrae. This is at the level of T5 for the mid thoracic manipulation and at the level of T9 for the lower thoracic manipulation. The therapist asks the patient to inhale fully and exhale completely. The therapist follows the patient through the exhalation and applied a downward pressure to take out soft tissue slack. At the end of the exhalation, the therapist applies a high-velocity, low-amplitude thrust to achieve the manipulation.



The cervicothoracic junction manipulation is applied with the patient seated. The patient laces their fingers behind their neck. The therapist position is behind the patient. The therapist laces their arms through the patients arms and clasps their hands near the region of C7-T1. The patient applies one side of the chest as a fulcrum to the patients upper thoracic region. The patient is instructed to inhale, followed by a complete exhalation. The therapist takes out the soft tissue slack into thoracic extension as the patient exhales and applies a distracting high-velocity, low-amplitude thrust in the cephalad direction.

Figure 3. Images and descriptions of the thoracic SMT techniques utilized within this study.



a.



b.

Figure 4. Pressure pain threshold measurements at the deltoid (a) and the lower trapezius (b) muscles.

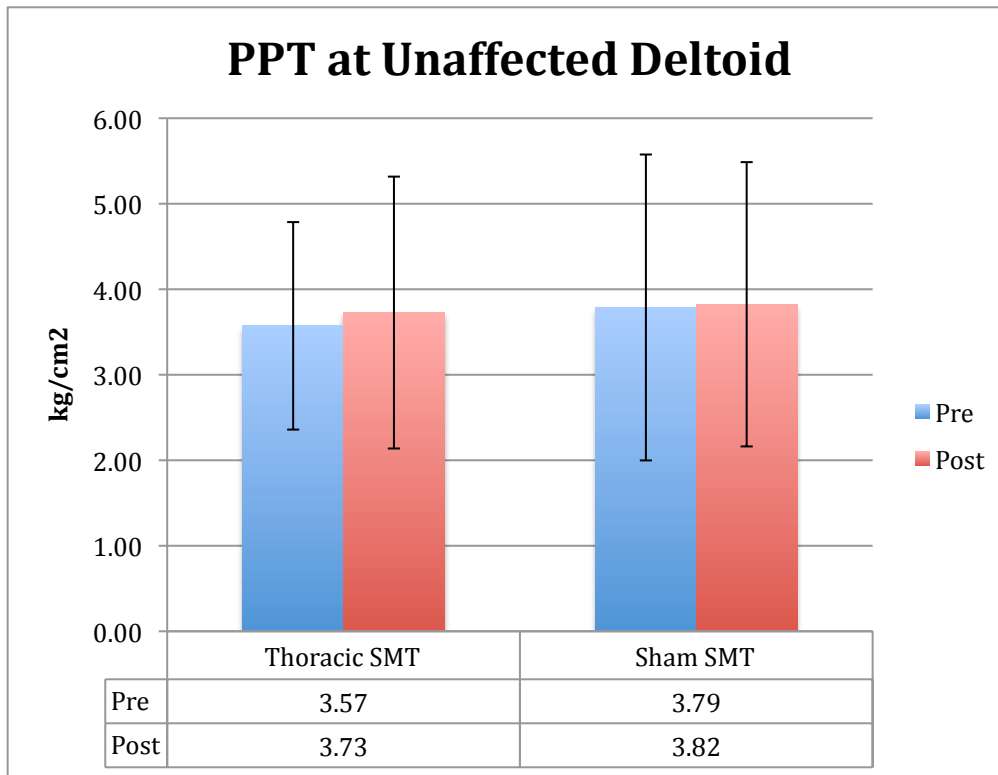
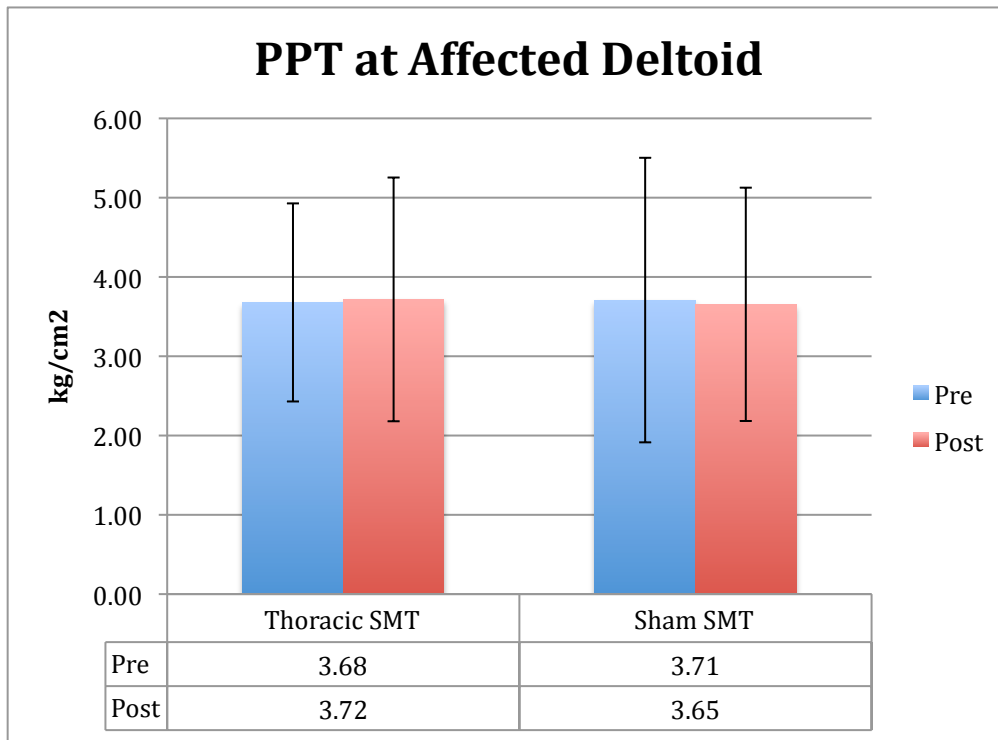


Figure 5. Pressure Pain Threshold (PPT) at the deltoid.

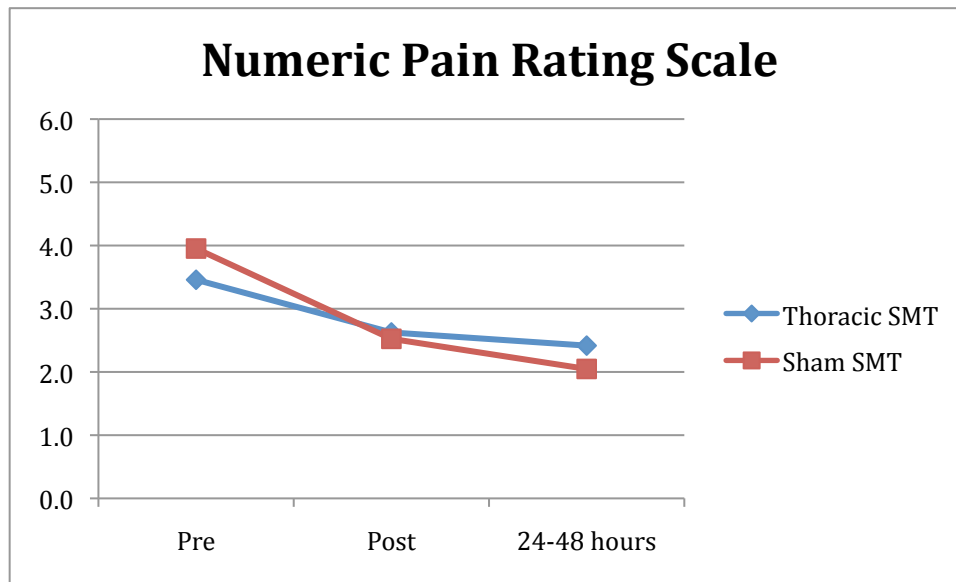


Figure 6. Numeric Pain Rating Scale (NPRS) mean values pre-treatment (Pre), post-treatment (Post), and at 24-48 hour follow-up (24-48 hours) for each treatment group.

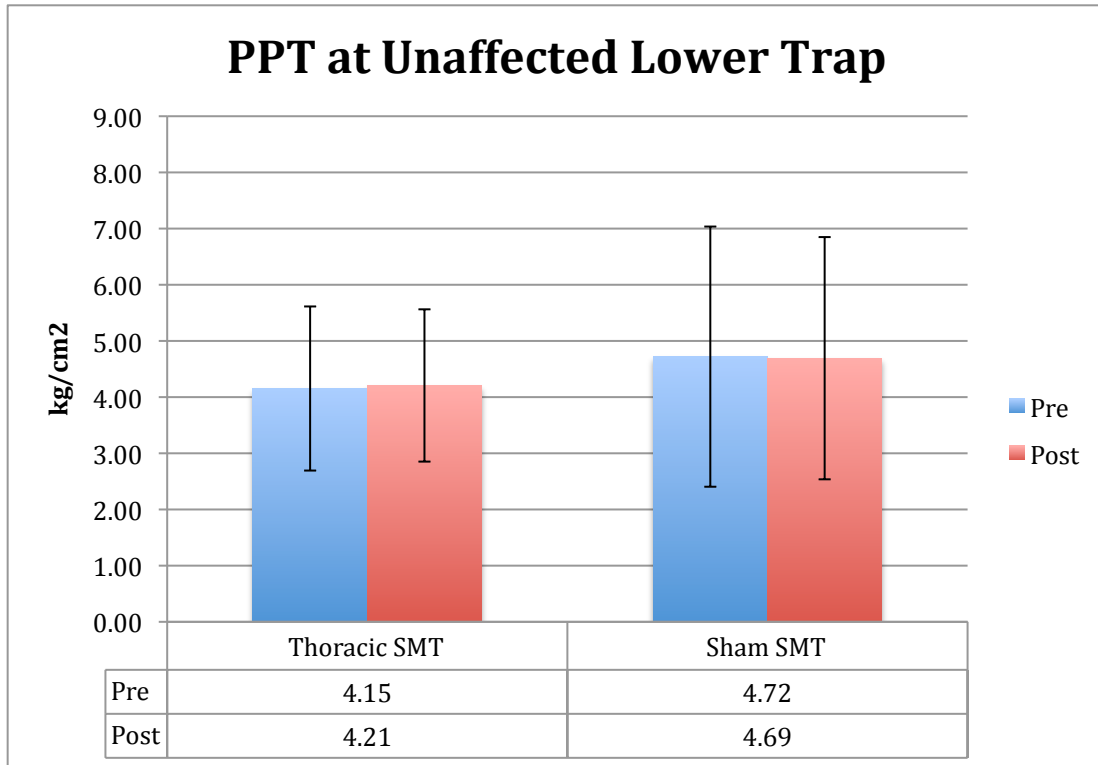
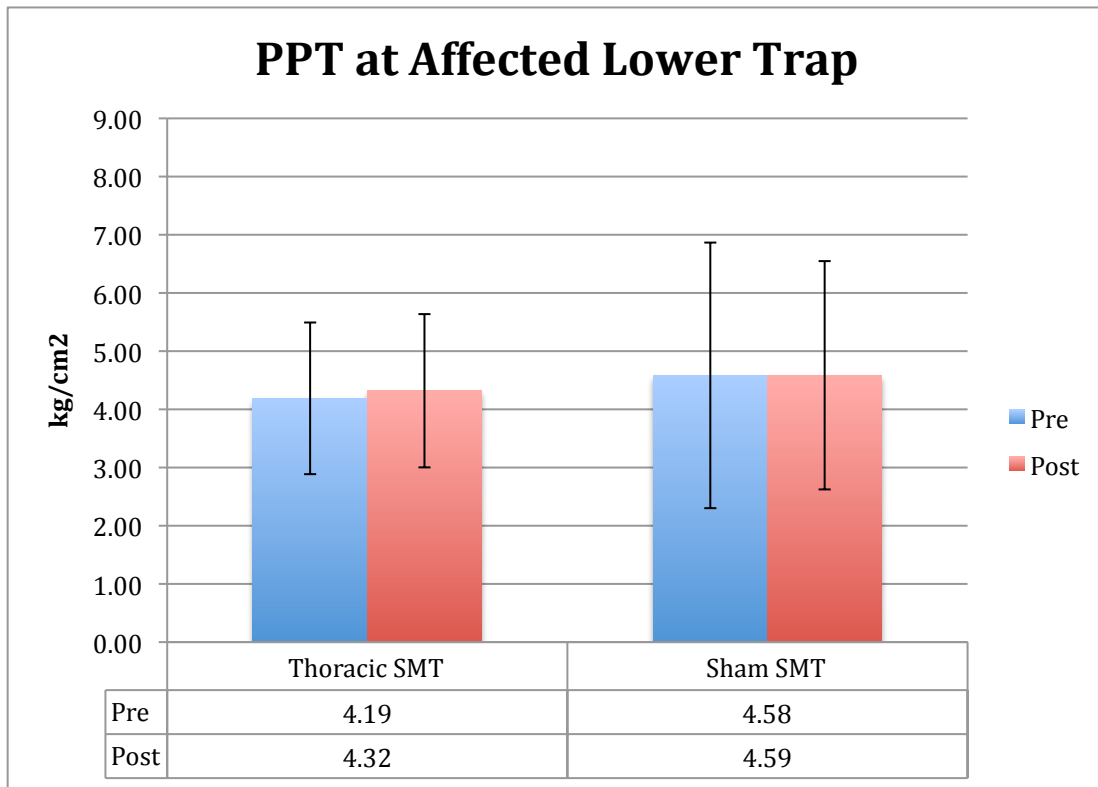


Figure 7. Pressure Pain Threshold (PPT) at the lower trapezius.

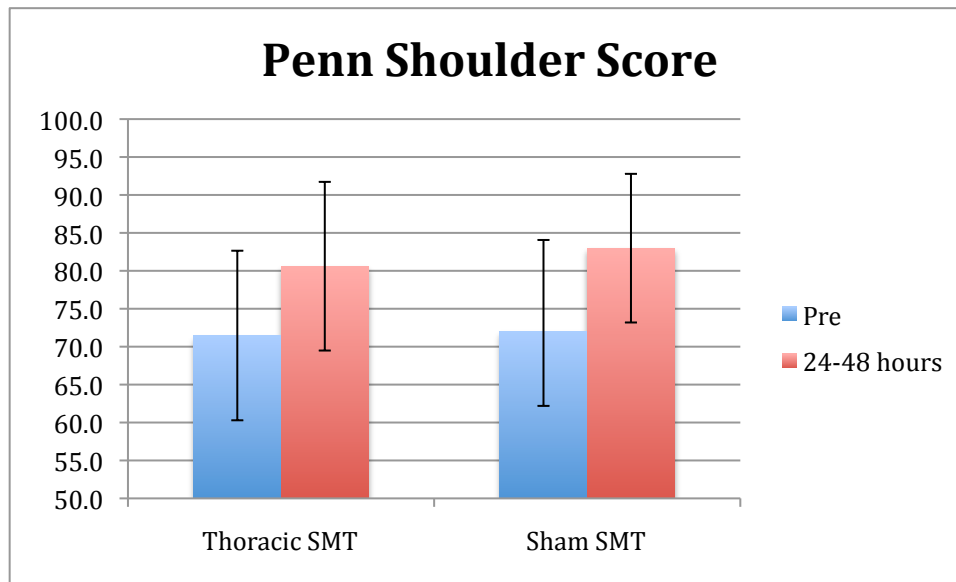


Figure 8. Penn shoulder scores for each treatment group pre-treatment (Pre) and at 24-48 hour follow-up (24-48 hours).

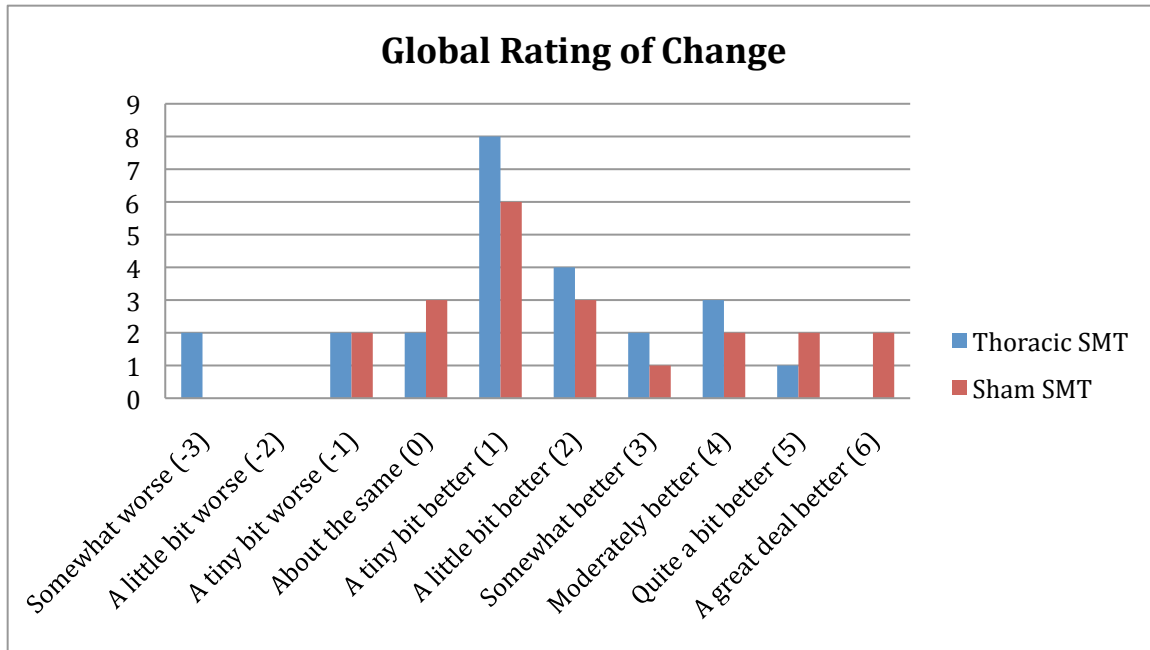


Figure 9. Frequency counts for Global Rating of Change (GROC) responses in each treatment group.

Table 1. Participant Characteristics (mean \pm standard deviation): age (years), symptom duration (months), BMI (kg/m²), Fear Avoidance Beliefs Questionnaire (FABQ) work scale (scored 0-24), and FABQ physical activity scale (scored 0-42).

	Participant Characteristics		p-value
	SMT (n=24)	Sham SMT (n=21)	
Age (years) range	31.1 \pm 12.3 18-59	31.2 \pm 12.1 18-56	p = 0.97
Symptom duration (months)	40.2 \pm 65.9	41.2 \pm 56.5	p = 0.96
Acute/ subacute (0 -12 weeks)	3 (13%)	2 (10%)	
Chronic (> 12 weeks)	21 (87%)	19 (90%)	
Female, n (%)	14 (58%)	9 (43%)	p = 0.38
BMI (kg/ m ²) Range	25.7 \pm 5.8 18.2-39.6	27.1 \pm 5.9 19.6-40.5	p = 0.44
FABQ work*	4.5 \pm 5.2	8.0 \pm 10.4	p = 0.14
FABQ physical activity*	14.5 \pm 4.3	15.2 \pm 5.5	p = 0.64

Table 2. Pressure Pain Threshold at the deltoid and lower trapezius pre-treatment and post-treatment in the thoracic SMT and sham SMT treatment groups. Values are in kg/cm² ± standard deviation.

Pressure Pain Threshold							
Location	Thoracic SMT				Sham SMT		
Deltoid	Pre		Post		Pre		Post
Affected side	3.68	± 1.25	3.72	± 1.54	3.71	± 1.79	3.65 ± 1.47
Unaffected side	3.57	± 1.21	3.73	± 1.59	3.79	± 1.79	3.82 ± 1.66
Lower Trapezius							
Affected side	4.19	± 1.30	4.32	± 1.32	4.58	± 2.28	4.59 ± 1.96
Unaffected side	4.15	± 1.46	4.21	± 1.36	4.72	± 2.32	4.69 ± 2.16

Table 3. Patient-rated outcomes on the numeric pain rating scale (NPRS), Penn Shoulder Score (Penn), and global rating of change (GROC). Time points for ratings are indicated as pre-treatment (Pre), post-treatment (Post), and 24-48 hour follow-up (24-48 hours). The scores (\pm standard deviation) are reported for each group. Score range is indicated next to each outcome instrument.

Patient-rated Outcomes						
	Pre		Post		24-48 hours	
NPRS (0-10)						
Thoracic SMT	3.5	± 1.4	2.6	± 1.8	2.4	± 1.6
Sham SMT	4.0	± 1.4	2.5	± 2.1	2.0	± 1.5
Penn (0-100)						
Thoracic SMT	71.4	± 11.2			80.6	± 11.1
Sham SMT	72.0	± 12.1			83.0	± 9.8
GROC (-7 to 7)						
Thoracic SMT					1.3	± 2.0
Sham SMT					2.0	± 2.2

Table 4. Results from statistical analysis of pressure pain threshold (PPT). The region tested and the side (affected or unaffected) are indicated. LT=Lower Trapezius.

Factor	df	Pressure Pain Thresholds							
		Deltoid - Affected		Deltoid - Unaffected		LT - Affected		LT - Unaffected	
		F Ratio	p-value	F Ratio	p-value	F Ratio	p-value	F Ratio	p-value
Group	1, 42	0.3	0.579	0.0	0.886	0.2	0.678	0.5	0.503
Time	1, 43	0.0	0.940	0.8	0.372	0.3	0.569	0.0	0.890
Group x Time	1, 43	0.2	0.655	0.3	0.583	0.3	0.580	0.2	0.671

Table 5. Statistical results from patient-rated outcomes of pain (NPRS) and function (Penn)

Numeric Pain Rating Scale (NPRS)

Factor	df	F Ratio	p-value
group	1, 43	0.0	0.984
Time	2, 86	15.8	<0.001*
group*Time	2, 86	1.3	0.278

Penn Shoulder Score (Penn)

Factor	df	F Ratio	p-value
group	1, 43	0.2	0.627
Time	1, 43	53.5	<0.001*
group*Time	1, 43	0.4	0.518

Chapter 5: Conclusion of Dissertation

The purpose of this dissertation research was to examine the affects of thoracic spinal manipulative therapy (SMT) on thoracic spine and scapular kinematics, thoracic excursion, and pressure pain sensitivity in patients with subacromial pain syndrome. Several single-arm clinical trials have reported clinical improvements with the use of thoracic SMT in treating patients with shoulder pain.^{14, 61, 79} Additionally, evidence exists in randomized clinical trials showing that thoracic SMT as part of a multi-modal manual therapy treatment approach leads to greater clinical improvements in patients receiving manual therapy compared to treatment groups receiving rehabilitative exercise and primary care treatments for shoulder pain.^{3, 6, 91} One previous single-arm trial has assessed the affects of thoracic SMT on scapular kinematics and trunk range of motion measurements and found only a small, and clinically insignificant, increase in scapular upward rotation following treatment.⁶³ That study also reported improvements in patient rated outcomes of pain and Penn scores.⁶³ These single-arm trials lacked a control group from which to draw direct comparisons.

Manual therapy has been shown to reduce the symptoms of shoulder pain.^{3, 4, 6, 10, 74, 75, 91} Clinically, manual therapy may be directed at the shoulder or the axial skeleton based on patient presentation and clinical exam findings. There are a multitude of possible mechanisms by which manual therapy intervention may help to improve the symptoms of musculoskeletal pain. Researchers have suggested that the effects of manual therapy may involve biomechanical and/or neurophysiologic mechanisms, and both types of variables should be included in studies of

manual therapy.^{9, 63} Therefore, this research assessed biomechanical factors at the thoracic spine and shoulder in response to thoracic manipulation, as well as pressure pain sensitivity over the deltoid and the lower trapezius muscles. This allowed for comparisons at the affected region of the shoulder and the region of application of treatment, in close proximity to the thoracic spine.

Chapter 2 provided a systematic review of randomized controlled trials (RCT) that used manual techniques at the shoulder and the thoracic spine in treating shoulder pain symptoms. Improvements in patient-rated outcomes were seen more often in the studies that incorporated thoracic SMT as part of the manual therapy intervention.^{3, 6, 91} The RCTs that applied treatment only at the shoulder girdle provided mixed results with respect to patient-rated outcomes.^{2, 4, 10, 19, 20, 38, 62, 74, 75, 92} To date, there has not been a published randomized clinical trial examining thoracic SMT alone as a treatment for shoulder pain.

The only previous study to assess immediate scapular kinematic changes in response to thoracic SMT lacked a comparator.⁶³ Similarly, two clinical trials assessing the immediate effects of thoracic SMT on shoulder pain also lacked comparator groups.^{14, 79} Therefore, the research for this dissertation compared kinematic changes at the thoracic spine and shoulder, as well patient-rated outcomes from the treatment of subacromial pain syndrome with thoracic SMT versus a sham SMT. Chapter 3 of this dissertation reported the findings of the thoracic spine and shoulder kinematics during arm elevation, as well as thoracic excursion following thoracic SMT. There were no differences noted between thoracic SMT or the sham thoracic SMT treatment groups in any of the thoracic or scapular variable, but both treatment groups showed greater scapular external rotation during the arm elevation task following treatment. This study assessed thoracic kinematics during an arm elevation task, as well as a measure of overall excursion from maximum flexion to maximum extension. Unlike the measure of thoracic displacement in

relation to a global reference that was measured by Muth et al.,⁶³ this dissertation research used a static measure of excursion of the thoracic spine motion based on angular measurement of this region of the spine rather than their measure of displacement of the thoracic relative to the global coordinate system. We also measured active thoracic kinematics during an arm elevation activity. Similarly to the results reported by Muth et al., we found no differences in thoracic motion with thoracic excursion or thoracic kinematics during the arm elevation task.

A study in patients with neck pain measuring pressure pain thresholds (PPT) at the neck, elbow, and leg following treatment with either cervical or thoracic SMT found improvements in both groups but no differences between the treatment groups.⁵² The use of cervical SMT in isolation has also shown decreases in pressure pain sensitivity at the cervical region and regions innervated by cervical spinal levels in people with musculoskeletal pain.^{27, 31, 51, 52, 88} However, this region specific effect was not seen at the lumbar region following lumbar manipulation.^{23, 28} Chapter 4 of this dissertation focused on examining changes in PPT taken at the shoulder (over the deltoid) and at the thoracic region (over the lower trapezius) in comparison to patient-rated outcomes. Despite improvements noted in patient-rated pain, Penn shoulder scale, and global rating of changes that occurred in both the thoracic and sham SMT groups, no change in PPT was found to accompany these improvements. It is possible that the level specific results seen with respect to cervical manipulation may not be seen with treatment of the thoracic spine. It is also possible that the mechanism of reduction of shoulder pain may involve neurophysiologic mechanisms that may be better assessed by methods of experimental pain measurement other than the mechanical stimulus from pressure algometry.

Clinical Implications

The results of this research have implications for clinicians using thoracic SMT to treat patients with shoulder pain. The patients who participated within this research showed decreases in pain, improvements in shoulder function, and positive ratings of change following treatment with a single dose of thoracic SMT or a sham thoracic SMT. However, there were no significant differences between the two treatment groups in the mechanistic measures of scapular or thoracic kinematics, thoracic excursion, or pressure pain sensitivity at the thoracic region or the shoulder. Based on the lack of difference in mechanistic measures between the treatment groups, the improvements noted in patient-rated outcomes may be due in part to placebo effect, positive contributions from manual contact, interaction with a healthcare provider, or the natural course of disease. It is also possible that a single dose of thoracic SMT may lead to changes that are perceivable by the patient but not yet measurable within the design of this study. Clinically, manual therapy interventions are typically provided in multiple doses over time, as well as combined with other therapeutic modalities. Therefore, the positive changes in patient-rated outcomes observed in this study could have been further enhanced with multiple treatments over time or in combination with other therapeutic modalities.

The lack of significant changes in scapular and thoracic kinematics and thoracic excursion leads to question whether a biomechanical model is the most appropriate method of assessing patients for treatment with thoracic SMT. It is possible that particular medical history or examination findings may be predictors for patients who respond to manual therapy for musculoskeletal disorders. Studies examining the effects of SMT techniques at the thoracic spine for shoulder pain and the lumbar spine for low back pain have reported a cluster of symptoms from patient history and clinical exam findings that predict success with SMT.^{33, 61} It

is also possible that predictive variables may identify individuals with a natural history that leads to quicker symptom resolution with treatment rather than a positive response to SMT.

Researches have noted that SMT and manual therapy in general may have several mechanistic affects that lead to positive patient outcomes.^{7, 9, 37} Therefore, improvements in patient-rated outcomes in the absence of significant changes in kinematics or pressure pain sensitivity may mean that thoracic SMT has benefits for patients with shoulder pain through mechanisms other than those measured in this study.

Future Research

Further research is needed to assess the mechanisms of thoracic SMT in patients with shoulder pain. Clinical trials noting positive improvements in shoulder pain from thoracic SMT have used multiple treatment doses.^{3, 6, 61, 91} Therefore, future research examining changes in kinematics following SMT should examine changes over time following multiple treatments rather than just immediate effects from a single dose of treatment. Comparisons of treatments such as exercise with and without augmentation with thoracic SMT may also help to discern additional mechanistic effects that could be provided by thoracic SMT. It is possible that factors associated with patient history and clinical exam findings may influence or predict success with treatment of shoulder pain using thoracic SMT.⁶¹ Future research should examine changes in kinematics or neurophysiologic variables in groups of patients with shoulder pain who respond to thoracic SMT compared to those who do not. In light of the findings within this research project that thoracic SMT and sham SMT led to similar improvements in patient-rated outcomes, use of a control group receiving another treatment intervention or a natural history group (no treatment) should also be considered in developing future studies.

References

1. Albuquerque-Sendin F, Camargo PR, Vieira A, Salvini TF. Bilateral myofascial trigger points and pressure pain thresholds in the shoulder muscles in patients with unilateral shoulder impingement syndrome: a blinded, controlled study. *Clin J Pain*. 2013;29:478-486.
2. Atkinson M, Mathews R, Brantingham JW, et al. A randomized controlled trial to assess the efficacy of shoulder manipulation vs. placebo in the treatment of shoulder pain due to rotator cuff tendinopathy. *J Am Chiropractic Assoc*. 2008;45:11-26.
3. 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.
4. Barbosa RI, Goes R, Mazzer N, Fonseca MCR. The influence of joint mobilization on tendinopathy of the biceps brachii and supraspinatus muscles. *Rev Bras Fisioter*. 2008;12:298-303.
5. Bennell K, Wee E, Coburn S, et al. Efficacy of standardised manual therapy and home exercise programme for chronic rotator cuff disease: randomised placebo controlled trial. *Bmj*. 2010;340:c2756.
6. 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.

7. Bialosky JE, Bishop MD, George SZ, Robinson ME. Placebo response to manual therapy: something out of nothing? *J Man Manip Ther.* 2011;19:11-19.
8. 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.
9. 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.
10. Bialoszewski D, Zaborowski G. Usefulness of manual therapy in the rehabilitation of patients with chronic rotator cuff injuries. Preliminary report. *Ortop Traumatol Rehabil.* 2011;13:9-20.
11. Bishop MD, Beneciuk JM, George SZ. Immediate reduction in temporal sensory summation after thoracic spinal manipulation. *Spine J.* 2011;11:440-446.
12. Boal RW, Gillette RG. Central neuronal plasticity, low back pain and spinal manipulative therapy. *J Manipulative Physiol Ther.* 2004;27:314-326.
13. Borstad JD, Ludewig PM. Comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane. *Clin Biomech (Bristol, Avon).* 2002;17:650-659.
14. 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.

15. Brantingham JW, Cassa TK, Bonnefin D, et al. Manipulative therapy for shoulder pain and disorders: expansion of a systematic review. *J Manipulative Physiol Ther*. 2011;34:314-346.
16. Broadhurst NA, Barton CA, Yelland LN, Martin DK, Beilby JJ. Managing shoulder pain in general practice--the value of academic detailing. *Aust Fam Physician*. 2006;35:751-752.
17. Campbell BD, Snodgrass SJ. The effects of thoracic manipulation on posteroanterior spinal stiffness. *J Orthop Sports Phys Ther*. 2010;40:685-693.
18. Chaban VV. Peripheral sensitization of sensory neurons. *Ethn Dis*. 2010;20:S1-3-6.
19. Chen JF, Ginn KA, Herbert RD. Passive mobilisation of shoulder region joints plus advice and exercise does not reduce pain and disability more than advice and exercise alone: a randomised trial. *Aust J Physiother*. 2009;55:17-23.
20. Conroy DE, Hayes KW. The effect of joint mobilization as a component of comprehensive treatment for primary shoulder impingement syndrome. *J Orthop Sports Phys Ther*. 1998;28:3-14.
21. Coronado RA, Kindler LL, Valencia C, George SZ. Thermal and pressure pain sensitivity in patients with unilateral shoulder pain: comparison of involved and uninvolved sides. *J Orthop Sports Phys Ther*. 2011;41:165-173.
22. Coronado RA, Simon CB, Valencia C, George SZ. Experimental Pain Responses Support Peripheral and Central Sensitization in Patients With Unilateral Shoulder Pain. *Clin J Pain*. 2013;[Epub ahead of print, DOI 10.1097/AJP.0b013e318287a2a4]

23. Cote P, Mior SA, Vernon H. The short-term effect of a spinal manipulation on pain/pressure threshold in patients with chronic mechanical low back pain. *J Manipulative Physiol Ther.* 1994;17:364-368.
24. Crawford HJ, Jull GA. The influence of thoracic posture and movement on range of arm elevation. *Physiotherapy Theory and Practice.* 1993;9:143-148.
25. Crosbie J, Kilbreath SL, Hollmann L, York S. Scapulohumeral rhythm and associated spinal motion. *Clin Biomech (Bristol, Avon).* 2008;23:184-192.
26. Culham E, Peat M. Functional anatomy of the shoulder complex. *J Orthop Sports Phys Ther.* 1993;18:342-350.
27. de Camargo VM, Albuquerque-Sendin F, Berzin F, Stefanelli VC, de Souza DP, Fernandez-de-las-Penas C. Immediate effects on electromyographic activity and pressure pain thresholds after a cervical manipulation in mechanical neck pain: a randomized controlled trial. *J Manipulative Physiol Ther.* 2011;34:211-220.
28. de Oliveira RF, Liebano RE, Costa Lda C, Rissato LL, Costa LO. Immediate effects of region-specific and non-region-specific spinal manipulative therapy in patients with chronic low back pain: a randomized controlled trial. *Phys Ther.* 2013;93:748-756.
29. 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.
30. Fernandez-Carnero J, Cleland JA, Arbizu RL. Examination of motor and hypoalgesic effects of cervical vs thoracic spine manipulation in patients with lateral epicondylalgia: a clinical trial. *J Manipulative Physiol Ther.* 2011;34:432-440.

31. Fernandez-Carnero J, Fernandez-de-las-Penas C, Cleland JA. Immediate hypoalgesic and motor effects after a single cervical spine manipulation in subjects with lateral epicondylalgia. *J Manipulative Physiol Ther.* 2008;31:675-681.
32. Fernandez-de-Las-Penas C, Alonso-Blanco C, Cleland JA, Rodriguez-Blanco C, Albuquerque-Sendin F. Changes in pressure pain thresholds over C5-C6 zygapophyseal joint after a cervicothoracic junction manipulation in healthy subjects. *J Manipulative Physiol Ther.* 2008;31:332-337.
33. Flynn T, Fritz J, Whitman J, et al. A clinical prediction rule for classifying patients with low back pain who demonstrate short-term improvement with spinal manipulation. *Spine (Phila Pa 1976).* 2002;27:2835-2843.
34. 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;7:68-77.
35. Greenman PE. *Principles of manual medicine.* 2nd. Baltimore: Williams & Wilkins; 1996;75-91.
36. Gumina S, Di Giorgio G, Postacchini F, Postacchini R. Subacromial space in adult patients with thoracic hyperkyphosis and in healthy volunteers. *Chir Organi Mov.* 2008;91:93-96.
37. Isabel de-la-Llave-Rincon A, Puentedura EJ, Fernandez-de-Las-Penas C. Clinical presentation and manual therapy for upper quadrant musculoskeletal conditions. *J Man Manip Ther.* 2011;19:201-211.

38. Kachingwe AF, Phillips B, Sletten E, Plunkett SW. Comparison of manual therapy techniques with therapeutic exercise in the treatment of shoulder impingement: a randomized controlled pilot clinical trial. *J Man Manip Ther.* 2008;16:238-247.
39. Kandel ER, Schwartz JH, Jessell TM. *Principles of neural science.* 4th. New York: McGraw-Hill, Health Professions Division; 2000;473-491.
40. 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.
41. 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.
42. Kulig K, Landel R, Powers CM. Assessment of lumbar spine kinematics using dynamic MRI: a proposed mechanism of sagittal plane motion induced by manual posterior-to-anterior mobilization. *J Orthop Sports Phys Ther.* 2004;34:57-64.
43. Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther.* 2006;36:485-494.
44. Lewis JS, Valentine RE. Clinical measurement of the thoracic kyphosis. A study of the intra-rater reliability in subjects with and without shoulder pain. *BMC Musculoskelet Disord.* 2010;11:39.
45. Lin JJ, Hsieh SC, Cheng WC, Chen WC, Lai Y. Adaptive patterns of movement during arm elevation test in patients with shoulder impingement syndrome. *J Orthop Res.* 2011;29:653-657.

46. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther.* 2000;80:276-291.
47. Ludewig PM, Cook TM, Nawoczenski DA. Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. *J Orthop Sports Phys Ther.* 1996;24:57-65.
48. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther.* 2009;39:90-104.
49. 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;29:574-583; discussion 584-576.
50. Maitland GD. *Maitland's Vertebral Manipulation.* 7th. New York: Elsevier; 2005;1-15.
51. Mansilla-Ferragut P, Fernandez-de-Las Penas C, Albuquerque-Sendin F, Cleland JA, Bosca-Gandia JJ. Immediate effects of atlanto-occipital joint manipulation on active mouth opening and pressure pain sensitivity in women with mechanical neck pain. *J Manipulative Physiol Ther.* 2009;32:101-106.
52. Martinez-Segura R, De-la-Llave-Rincon AI, Ortega-Santiago R, Cleland JA, Fernandez-de-Las-Penas C. Immediate changes in widespread pressure pain sensitivity, neck pain, and cervical range of motion after cervical or thoracic thrust manipulation in patients with bilateral chronic mechanical neck pain: a randomized clinical trial. *J Orthop Sports Phys Ther.* 2012;42:806-814.

53. McClatchie L, Laprade J, Martin S, Jaglal SB, Richardson D, Agur A. Mobilizations of the asymptomatic cervical spine can reduce signs of shoulder dysfunction in adults. *Man Ther.* 2009;14:369-374.
54. McClure P, Greenberg E, Kareha S. Evaluation and management of scapular dysfunction. *Sports Med Arthrosc.* 2012;20:39-48.
55. 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.
56. 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.
57. 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.
58. Meislin RJ, Sperling JW, Stitik TP. Persistent shoulder pain: epidemiology, pathophysiology, and diagnosis. *Am J Orthop (Belle Mead NJ).* 2005;34:5-9.
59. Melzack R, Wall PD. Pain mechanisms: a new theory. *Science.* 1965;150:971-979.
60. Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clin Biomech (Bristol, Avon).* 2003;18:369-379.
61. Mintken PE, Cleland JA, Carpenter KJ, Bieniek ML, Keirns M, Whitman JM. Some factors predict successful short-term outcomes in individuals with shoulder pain

- receiving cervicothoracic manipulation: a single-arm trial. *Phys Ther.* 2010;90:26-42.
62. Munday SL, Jones A, Brantingham JW, Globe G, Jensen M, Price JL. A randomized, single-blinded, placebo-controlled trial to evaluate the efficacy of chiropractic shoulder girdle adjustment in the treatment of shoulder impingement syndrome. *J Am Chiropractic Assoc.* 2007;44:6-15.
63. Muth S, Barbe MF, Lauer R, McClure PW. The effects of thoracic spine manipulation in subjects with signs of rotator cuff tendinopathy. *J Orthop Sports Phys Ther.* 2012;42:1005-1016.
64. Norlander S, Aste-Norlander U, Nordgren B, Sahlstedt B. Mobility in the cervico-thoracic motion segment: an indicative factor of musculo-skeletal neck-shoulder pain. *Scand J Rehabil Med.* 1996;28:183-192.
65. Norlander S, Gustavsson BA, Lindell J, Nordgren B. Reduced mobility in the cervico-thoracic motion segment--a risk factor for musculoskeletal neck-shoulder pain: a two-year prospective follow-up study. *Scand J Rehabil Med.* 1997;29:167-174.
66. Paris SV. A history of manipulative therapy through the ages and up to the current controversy in the United States. *Journal of Manual and Manipulative Therapy.* 2000;8:66-77.
67. Paul TM, Soo Hoo J, Chae J, Wilson RD. Central hypersensitivity in patients with subacromial impingement syndrome. *Arch Phys Med Rehabil.* 2012;93:2206-2209.
68. Pope DP, Croft PR, Pritchard CM, Silman AJ, Macfarlane GJ. Occupational factors related to shoulder pain and disability. *Occup Environ Med.* 1997;54:316-321.

69. Ross JK, Bereznick DE, McGill SM. Determining cavitation location during lumbar and thoracic spinal manipulation: is spinal manipulation accurate and specific? *Spine (Phila Pa 1976)*. 2004;29:1452-1457.
70. Roy JS, Moffet H, Hebert LJ, Lirette R. Effect of motor control and strengthening exercises on shoulder function in persons with impingement syndrome: a single-subject study design. *Man Ther*. 2009;14:180-188.
71. Roy JS, Moffet H, Hebert LJ, St-Vincent G, McFadyen BJ. The reliability of three-dimensional scapular attitudes in healthy people and people with shoulder impingement syndrome. *BMC Musculoskelet Disord*. 2007;8:49 [DOI 10.1186/1471-2474-8-49]..
72. Roy JS, Moffet H, McFadyen BJ. The effects of unsupervised movement training with visual feedback on upper limb kinematic in persons with shoulder impingement syndrome. *J Electromyogr Kinesiol*. 2010;20:939-946.
73. Seitz AL, McClure PW, Finucane S, Boardman ND, 3rd, Michener LA. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? *Clin Biomech (Bristol, Avon)*. 2011;26:1-12.
74. Senbursa G, Baltaci G, Atay A. Comparison of conservative treatment with and without manual physical therapy for patients with shoulder impingement syndrome: a prospective, randomized clinical trial. *Knee Surg Sport Tr A*. 2007;15:915-921.
75. Senbursa G, Baltaci G, Atay OA. The effectiveness of manual therapy in supraspinatus tendinopathy. *Acta Orthop Traumatol Turc*. 2011;45:162-167.

76. Sobel JS, Kremer I, Winters JC, Arendzen JH, de Jong BM. The influence of the mobility in the cervicothoracic spine and the upper ribs (shoulder girdle) on the mobility of the scapulohumeral joint. *J Manipulative Physiol Ther.* 1996;19:469-474.
77. Sobel JS, Winters JC, Groenier K, Arendzen JH, Meyboom de Jong B. Physical examination of the cervical spine and shoulder girdle in patients with shoulder complaints. *J Manipulative Physiol Ther.* 1997;20:257-262.
78. Sterling M. Pressure algometry: what does it really tell us? *J Orthop Sports Phys Ther.* 2011;41:623-624.
79. 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.
80. Su KP, Johnson MP, Gracely EJ, Karduna AR. Scapular rotation in swimmers with and without impingement syndrome: practice effects. *Med Sci Sports Exerc.* 2004;36:1117-1123.
81. Sueki DG, Chaconas EJ. The effect of thoracic manipulation on shoulder pain: a regional interdependence model. *Phys Ther Rev.* 2011;16:399-408.
82. Surenkok O, Aytar A, Baltaci G. Acute effects of scapular mobilization in shoulder dysfunction: a double-blind randomized placebo-controlled trial. *J Sport Rehabil.* 2009;18:493-501.
83. Teys P, Bisset L, Vicenzino B. The initial effects of a Mulligan's mobilization with movement technique on range of movement and pressure pain threshold in pain-limited shoulders. *Man Ther.* 2008;13:37-42.

84. Theisen C, van Wagensveld A, Timmesfeld N, et al. Co-occurrence of outlet impingement syndrome of the shoulder and restricted range of motion in the thoracic spine--a prospective study with ultrasound-based motion analysis. *BMC Musculoskelet Disord*. 2010;11:135 [DOI 10.1186/1471-2474-11-135].
85. Theodoridis D, Ruston S. The effect of shoulder movements on thoracic spine 3D motion. *Clin Biomech (Bristol, Avon)*. 2002;17:418-421.
86. Thigpen CA, Padua DA, Morgan N, Kreps C, Karas SG. Scapular kinematics during supraspinatus rehabilitation exercise: a comparison of full-can versus empty-can techniques. *Am J Sports Med*. 2006;34:644-652.
87. Timmons MK, Thigpen CA, Seitz AL, Karduna AR, Arnold BL, Michener LA. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. *J Sport Rehabil*. 2012;21:354-370.
88. Vernon HT, Aker P, Burns S, Viljakaanen S, Short L. Pressure pain threshold evaluation of the effect of spinal manipulation in the treatment of chronic neck pain: a pilot study. *J Manipulative Physiol Ther*. 1990;13:13-16.
89. 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.
90. Wainner RS, Whitman JM, Cleland JA, Flynn TW. Regional interdependence: a musculoskeletal examination model whose time has come. *J Orthop Sports Phys Ther*. 2007;37:658-660.
91. 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.

92. Yiasemides R, Halaki M, Cathers I, Ginn KA. Does passive mobilization of shoulder region joints provide additional benefit over advice and exercise alone for people who have shoulder pain and minimal movement restriction? A randomized controlled trial. *Phys Ther*. 2011;91:178-189.

Vita

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