SUZANNE J. SNODGRASS, PhD[1] • DARREN A. RIVETT, PhD[2] • MICHELE STERLING, PhD[3,4] • BILL VICENZINO, PhD[4]

Dose Optimization for Spinal Treatment Effectiveness: A Randomized Controlled Trial Investigating the Effects of High and Low Mobilization Forces in Patients With Neck Pain

STUDY DESIGN: Randomized controlled trial.

OBJECTIVE: To determine if force magnitude during posterior-to-anterior mobilization affects immediate and short-term outcomes in patients with chronic, nonspecific neck pain.

BACKGROUND: The optimal dose of mobilization to effectively treat patients with neck pain is not known.

METHODS: Patients with neck pain of at least 3 months in duration (n = 64) were randomized to receive a single treatment of posterior-to-anterior mobilization applied with 30 N or 90 N of mean peak force (3 sets of 30 seconds) or a placebo (detuned laser) on the spinous process at the painful spinal level. Pressure pain threshold, pain measured with a visual analog scale (range, 0-100 mm), cervical range of motion, and spinal stiffness at the painful spinal level (measured with a custom device and normalized as a percentage of C7 stiffness) were assessed before, immediately after, and at a mean ± SD follow-up of 4.0 ± 1.8 days following treatment. Repeated-measures analysis of covariance and Bonferroni-adjusted post hoc tests determined group differences for each outcome measure after treatment and at follow-up.

RESULTS: At follow-up, the 90-N group had less pain than the 30-N group (mean difference, 11.3 mm; 95% confidence interval: 0.1, 22.6 mm; P = .048) and lower stiffness than the placebo group (mean difference, 17.5%; 95% confidence interval: 4.2%, 30.9%; P = .006). These differences were not present immediately after treatment. There were no significant between-group differences in pressure pain threshold or range of motion after treatment or at follow-up.

CONCLUSION: A specific dose of mobilization, in terms of applied force, appears necessary for reducing stiffness and potentially pain in patients with chronic neck pain. Changes were not observed immediately after mobilization, suggesting that its effects are not directly mechanical. Trial registration: Australian and New Zealand Clinical Trials Registry (http://www.anzctr.org.au/): ACTRN12611000374965.

LEVEL OF EVIDENCE: Therapy, level 1b–. *J Orthop Sports Phys Ther 2014;44(3):141-152. Epub 22 January 2014. doi:10.2519/jospt.2014.4778*

KEY WORDS: *biomechanics, cervical vertebrae, manual therapy, musculoskeletal manipulations, neck*

Approximately 30% to 50% of adults will experience neck pain over a 12-month period,[28] and many will seek physiotherapy treatment. In treating neck pain, physiotherapists commonly use passive joint mobilization,[31,41] which consists of manual oscillatory forces applied to the spine.[42] There is some evidence that passive joint mobilization is effective in treating patients with neck pain when it is combined with exercise,[22,29] and it appears to be more cost-effective than other treatments when societal factors, such as lost productivity, are considered.[40] However, the optimal dose of joint mobilization is not known, and the forces therapists apply when performing the same technique vary,[59] making it difficult to attribute treatment outcomes to a particular technique or dose.

The dose of manual therapy is charac-

[1]Discipline of Physiotherapy, School of Health Sciences, Faculty of Health and Medicine, The University of Newcastle, Callaghan, Australia. [2]School of Health Sciences, Faculty of Health and Medicine, The University of Newcastle, Callaghan, Australia. [3]Centre of National Research on Disability and Rehabilitation Medicine, University of Queensland, Herston, Australia. [4]Centre of Clinical Research Excellence in Spinal Pain, Injury and Health, University of Queensland, Brisbane, Australia. The study was approved by The University of Newcastle Human Research Ethics Committee. This study was supported by a grant from the Physiotherapy Research Foundation of the Australian Physiotherapy Association. The granting body was independent of the research team and had no influence on the study results or reporting. Michele Sterling receives a fellowship from the National Health and Medical Research Council of Australia. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. This trial is registered with the Australian and New Zealand Clinical Trials Registry (http://www.anzctr.org.au/): ACTRN12611000374965. Address correspondence to Dr Suzanne J. Snodgrass, Discipline of Physiotherapy, School of Health Sciences, The University of Newcastle, Hunter Building, Callaghan, NSW 2308 Australia. E-mail: Suzanne.Snodgrass@newcastle.edu.au

terized by the properties of the manual technique applied, the length of time it is applied during a treatment session, and the number and frequency of treatment sessions. The properties of passive joint mobilization include the force magnitude (maximum peak); force amplitude (difference between maximum peak and minimum trough) and direction of the applied force; the oscillation frequency at which the force is applied; and the displacement, or amount of movement, occurring during oscillation.[56] There is a nascent body of work on these mechanical properties in terms of patient responses to treatment. Preliminary evidence suggests that there is a critical level of manual force needed to produce a hypoalgesic effect in patients with lateral epicondylalgia following a "mobilization with movement" manual therapy technique at the elbow.[43] There is also some evidence that a higher rate of oscillation may increase the sympathoexcitatory effect that occurs following cervical spine mobilizations in asymptomatic individuals.[10] In addition, repeated sets of lumbar mobilization are reported to increase pressure pain thresholds (PPTs) compared to a single set in asymptomatic individuals.[46] To the contrary, varying the duration, amplitude, or frequency of oscillation of a lumbar mobilization does not influence the change in PPTs.[35,46,71] We are unaware of any studies of the effects of specific properties of a spinal mobilization, such as magnitude of force or oscillation frequency, on outcomes in patients with spinal pain.

Systematic reviews of manual therapy for neck pain indicate that research is needed to determine the optimal treatment characteristics and dosages of manual therapy for effectiveness.[22,23] This randomized controlled trial selects 1 property of mobilization, the magnitude of force, and applies it using 2 standardized force levels to determine if varying the force affects the treatment outcome. The aim was to determine whether the magnitude of force applied during posterior-to-anterior (PA) mobilization would affect immediate and short-term treatment outcomes in patients with chronic, nonspecific neck pain. Specifically, this study investigates whether applying a low- or high-force PA mobilization, or placebo treatment, results in differences in changes in PPTs, resting pain ratings, cervical range of motion (ROM), or cervical spine stiffness immediately after treatment, and whether these effects are maintained in the short term. This will assist in determining whether a specific dose of mobilization is needed to optimize the treatment of patients with chronic neck pain and provide evidence to guide physiotherapists in their application of mobilization.

METHODS

Study Design

Participants entering the study were randomized into 1 of 3 treatment groups: low-force mobilization, high-force mobilization, or placebo. Participants attended a single treatment session in a laboratory setting on The University of Newcastle (Australia) campus. Measurements were taken prior to treatment, immediately after treatment, and at a follow-up session approximately 4 days later. The study design and participant flow are illustrated in **FIGURE 1**.

Participants

Participants were individuals with chronic, nonspecific neck pain (greater than 3 months in duration), aged between 18 and 55 years. The upper age limit of 55 years was used to limit the potential of recruiting individuals with degenerative changes that could possibly affect the study outcome. Only individuals with a minimum resting pain of 3/10 on a numeric pain rating scale were included, to prevent floor effects and ensure homogeneity. Potential participants reported how long their neck pain had interfered with their normal work over the previous 4 weeks on a Likert scale with 5 response categories.[70] Only those who answered "moderately," "quite a bit," or "extremely" were included, whereas those who answered "not at all" or "a little bit" were excluded. Potential participants were also excluded if they had upper cervical pain or headache as their primary complaint, or if they had dizziness, a history of trauma related to the neck, surgery to the neck, diabetes, peripheral vascular disease, or referred arm pain past the acromion (ie, radiculopathy). They were also excluded if they had received any form of treatment in the previous 12 weeks that had a hands-on component (eg, physiotherapy, chiropractic, acupuncture, massage). Participants were recruited between April and October 2011 through advertisements in local publications, e-mails to university staff, and flyers posted around the campus where the study was conducted. Interested individuals responding to the advertisements were initially screened by telephone.

Participants were assigned to 1 of the 3 study groups (low-force PA mobilization, high-force PA mobilization, or placebo) through concealed allocation (sealed envelopes) and independent blocked randomization, using a random-number generator. One author enrolled patients in the study, while an independent research assistant performed the randomization and prepared the sealed envelopes, which were opened after baseline data collection by the physiotherapist performing the treatments. Participants were treated in a private treatment area and had no knowledge of treatments received by other participants. The study was approved by The University of Newcastle Human Research Ethics Committee. All participants gave informed consent to participate, and their rights were protected.

Treatment

A registered physiotherapist with more than 10 years of experience in musculoskeletal (outpatient orthopaedic) physiotherapy selected each participant's most painful spinal level using PA passive joint movement and participant response. A second experienced musculoskeletal

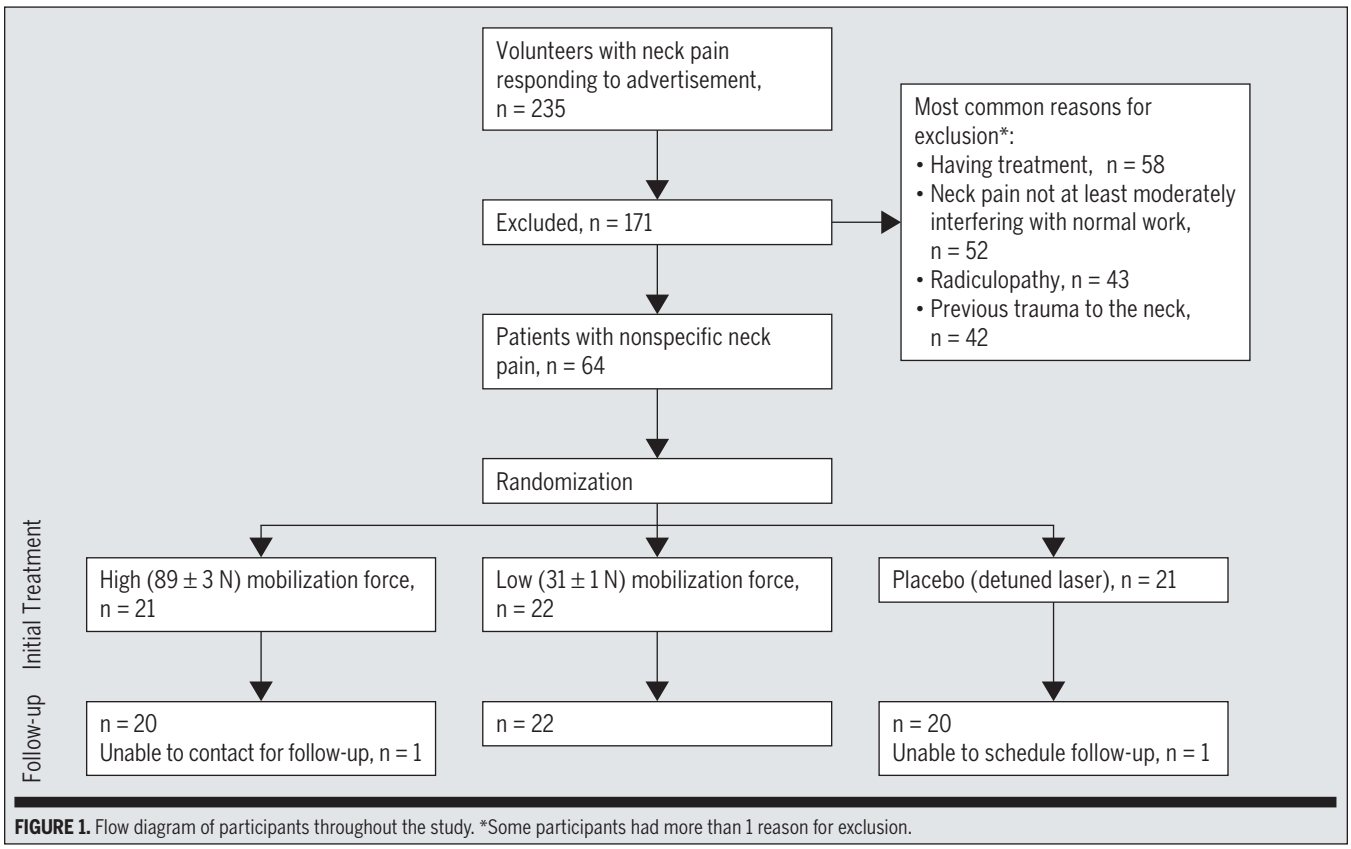

FIGURE 1. Flow diagram of participants throughout the study. *Some participants had more than 1 reason for exclusion.

physiotherapist (20 years) palpated the selected spinal level, and the identification (label) of the level was determined by consensus. Subsequently, the first therapist applied the standardized PA mobilization at either level of force or the placebo treatment. Participants in the active treatment groups received 1 session consisting of 3 sets of 1 minute of PA mobilization, applied with the thumbs to the spinous process[42] at the level judged by the therapist to be the most painful. This amount of mobilization is consistent with clinical practice[42] and previous studies in the cervical spine.[63,64] The low-force treatment group received PA mobilization with a 30-N mean peak force, whereas the high-force group received PA mobilization with a 90-N mean peak force. Peak forces were measured using load cells fitted to an instrumented treatment table on which the participant lay,[55] and the therapist used real-time feedback via a computer monitor to ensure mean peak force levels remained consistent.[60] Both force levels were applied with the therapist using the conceptual definition of a grade III mobilization, defined as "large amplitude movement moving into stiffness."[42] Oscillation frequency was standardized at 1.0 Hz for both force conditions, which is the average frequency used by physiotherapists when applying a grade III cervical mobilization.[59] The therapist was also able to monitor their oscillation frequency via the real-time feedback mechanism, which provided visual feedback (in the form of flashing colors if outside the target force or oscillation frequency). Force amplitude was expected to be relatively consistent with the magnitude of force applied,[59,71] though it could also be viewed on the monitor.

The high and low levels of force were selected based on previously published data.[58,59] Registered physiotherapists who regularly use PA mobilizations apply grade III techniques to the lower cervical spine using a mean peak force of 64.2 ± 28.6 N (range, 6.0-133.4 N, excluding 5 outliers confirmed using the Grubbs test).[52] A low force of 30 N and high force of 90 N were selected, being approximately 1 standard deviation below and above the mean peak force applied to C7 by the 116 practicing physiotherapists in a previous study.[59] The high force was expected to be tolerated by the majority of participants and was high enough to be recognized by most therapists as sufficiently different from the low force of 30 N. The low force of 30 N was high enough to be considered as "moving into stiffness" in the cervical spine[57] and low enough to be recognizably different from the high force of 90 N. The placebo treatment group received detuned-laser treatment for 3 sets of 1 minute. Detuned laser is an acceptable placebo treatment[25,30] and was plausible in a previous study in patients with cervicogenic pain and dizziness.[48] Though patients were informed that they might receive a placebo intervention, at the time of treatment the treating thera-

pist described all interventions as though they were genuine, including the potential beneficial and possible adverse effects of either mobilization or laser (the placebo). All patients were told that their intervention was known to be beneficial for some patients with their condition,[3] which blinded the patients as to whether they had received a genuine or placebo treatment.

Outcome Measurements

A third physiotherapist with 5 years of experience, who was blinded to participant group, performed all measurements. To blind the physiotherapist, the participants were instructed to refrain from revealing information about the treatment they received to the therapist conducting measurements, who was absent from the treatment area. The primary outcome was PPT, and the secondary outcomes were patient-reported resting pain, cervical ROM, and cervical spine stiffness. At each assessment, resting pain was recorded first, followed by ROM, PPT, and spinal stiffness. This order was selected due to the possible effects of each measurement on those measured beforehand. To describe the study population and allow comparison with previous research, participants completed the Neck Disability Index (NDI; scored out of 50 points) prior to measurement on the day of treatment. This was repeated at the follow-up session to monitor for changes.[11,68]

Pressure Pain Threshold PPT was measured using a JTECH algometer (Tracker Freedom Algometry; JTECH Medical, Salt Lake City, UT). PPT has demonstrated reliability,[47] correlates well with clinical status,[16] and is commonly used to assess immediate treatment effects.[8,15,64,71] Intrarater reliability of PPT measurements is reported to be good between sessions separated by 1 week (intraclass correlation coefficient [ICC]>0.87),[47] and ICCs of 0.93 to 0.96 have been reported for repeated PPT tests performed on the same day using the JTECH algometer.[71] Pressure was applied at 4 N/s using a 1-cm^2 indenter tip, corresponding to 40 kPa/s. Participants were instructed to press a switch at the moment the sensation of pressure from the algometer tip changed to a sensation of discomfort or pain. At this point, the patient stopped the test and the JTECH software recorded a value in Newtons (N), which was subsequently converted to kilopascals (kPa) for analysis. As patients with nonspecific neck pain are not usually sensitized to pain,[9,49] 3 landmarks were tested in random order: (1) adjacent to the spinous process at the treated spinal level on the right side, with the participant lying prone; (2) the right upper trapezius muscle, midway between C7 and the acromion, with the participant in sitting; and (3) the right median nerve trunk at the elbow, just medial to the biceps tendon, with the elbow in approximately 30° of flexion, the forearm resting on the plinth, and the participant sitting. The right side was tested on all participants, as previous research has shown that side-to-side differences are insignificant in individuals with nonspecific neck pain.[9] Each landmark was tested 3 times, with a 10-second rest between tests, and PPT scores were averaged. The PPT scores taken at each of the 3 landmarks and an overall sum of these were used for analysis. The reliability of PPT testing was assessed with ICCs for the triplicate measurements at each landmark at each time point, and the standard error of measurement was calculated using the standard deviation of the grand mean across time points.[47]

Pain Participants indicated their resting pain at baseline and follow-up by marking a 100-mm visual analog scale (VAS), anchored by "no pain" at 0 mm on the left and "worst pain imaginable" at 100 mm on the right. Participants also rated their level of comfort/discomfort with the treatment they received by marking a VAS anchored by "very comfortable" at 0 mm on the left and "very uncomfortable" at 100 mm on the right. Any adverse effects from treatment were recorded on patient data sheets. To determine whether the applied force of the mobilization was acceptable to participants, at the completion of the study participants were also asked whether they would be willing to have their assigned treatment again if they were attending physiotherapy.

Cervical ROM Cervical ROM was measured in the sagittal and horizontal planes using a cervical-range-of-motion instrument (CROM; Performance Attainment Associates, Lindstrom, MN). The CROM has excellent reported reliability over separate days (ICCs ranging from 0.89 to 0.98).[2] Each movement direction (flexion, extension, right rotation, and left rotation) was repeated 3 times and averaged. Measurements of sagittal and horizontal ROM were randomized to account for any possible effects of movement in one plane on movement in the other plane. Participants were instructed to move their head as far as possible in each direction. Sagittal ROM was the sum of degrees of flexion and extension. Rotation ROM was the sum of degrees of right and left rotation. Total ROM was the sum of degrees of sagittal and rotation ROM. After measurement in each movement direction, participants were asked to name their most painful movement direction from the 4 directions tested. Degrees of ROM at the first onset of pain in the most painful movement direction were then measured 3 times and averaged.

Spinal Stiffness Spinal stiffness was measured with a custom device that applied 5 cycles of standardized oscillatory force at a rate of 1 Hz/s. The standardized force was determined by the voltage supplied to the device's motor, which allowed the indenter rod applying the force to move 14 mm against a resistance equal to 70 N.[57] Resistance to the applied force (N) and displacement (mm), or the distance the indenter rod traveled, were recorded simultaneously. The first cycle of applied force was discarded,[44,50] and stiffness was defined as the slope of the linear portion of the force-displacement curve averaged over cycles 2 through 5 (N/mm).[53,57] The linear portion was determined by viewing the force-displacement curves across the sample and selecting a linear range ap-

propriate for all spinal levels measured. Spinal stiffness differs between spinal levels,[7,57,69] and thus the linear portion of the curve varied slightly between spinal levels. A single force range (15-50 N) for calculating stiffness was selected to allow comparisons across the sample, as stiffness differs when calculated for different portions of the force-displacement curve.[36] The stiffness measurement device has satisfactory accuracy and reliability (standard error of measurement for C7, 0.83 N/mm and for C2, 0.53 N/mm; for repeated measures, ICC = 0.84; 95% confidence interval [CI]: 0.74, 0.90). Details concerning the development and evaluation of this device have been previously reported.[57]

Stiffness was measured first at C7, then at the participant's painful spinal level. C7 was marked by the same experienced physiotherapist at each occasion of measurement (baseline, posttreatment, and follow-up) using standardized methods.[24,27,45] Stiffness at the painful spinal level was normalized as a percentage of stiffness at C7 (as measured at each time point), and this value was used in further analyses. Percentages less than 100% indicated that the painful spinal levels were less stiff than C7.

Data Analysis

Sample-size calculations indicated that 20 subjects per group were needed to detect a 10% difference in PPT between groups, with a variability in that difference score of 8%,[64] 90% power, and an alpha of .017. PPT was proposed as the primary outcome measure because it was expected to be more sensitive to initial changes following treatment[8,64,71] than resting pain (VAS).[32,33] Data were checked for normality prior to statistical analyses, which were performed per protocol. Descriptive statistics and counts were used to describe the sample. The mean peak mobilization forces applied to participants in the active treatment groups were averaged across participants in each group to determine if forces were applied at the correct mean peak force level and to calculate the amount of variance in applied force within each group. Participants' comfort levels with the applied treatments were compared using a 1-way analysis of variance.

Repeated-measures analyses of covariance with 2 factors, group (high force, low force, and placebo) and time (immediately after treatment and follow-up), were used to determine the effects of treatment on each outcome variable (PPT, pain, ROM, and stiffness) using baseline values as the covariates. A P value of .05 was considered significant. When the assumption of sphericity was not met, the Greenhouse-Geisser correction was used. For outcome variables with a significant time-by-group interaction, follow-up Bonferroni-adjusted (P<.017) post hoc tests were used to determine differences between the 3 treatment groups (high force versus low force, high force versus placebo, and low force versus placebo) immediately after treatment and at follow-up approximately 4 days later. Cases with missing data were excluded on an analysis-by-analysis basis. All analyses were performed in SPSS Statistics Version 19.0 (IBM Corporation, Armonk, NY).

RESULTS

Sixty-four participants entered the study after the volunteers who responded to recruitment advertising were screened (**FIGURE 1**). The most common reasons for exclusion were recent hands-on treatment, neck pain that did not at least moderately interfere with normal work, the presence of radiculopathy, and previous trauma to the neck (most often whiplash). Participant characteristics are described in **TABLE 1**. There were no meaningful differences between the 3 treatment groups in baseline characteristics. All participants received the intervention to which they were randomly assigned. Two participants were lost to follow-up, 1 in the high-force group and 1 in the placebo group. All other participants had complete data for the primary outcome measure, with the exception of 1 participant, whose follow-up measurement of spinal stiffness was lost due to compromised electronic data recording.

The average of the mean peak forces applied for each treatment group (recorded across all participants) was 30.8 N (95% CI: 30.7, 31.0 N) for the low-force group and 88.6 N (95% CI: 87.4, 89.8 N) for the high-force group. Participants were less comfortable with the high-force mobilization compared to the placebo intervention (comfort VAS mean ± SD, 48.1 ± 29.1 mm and 5.5 ± 9.7 mm, respectively; mean difference, 42.5 mm; 95% CI: 24.2, 60.9 mm; P<.001). There was no statistical difference in the level of comfort with treatment between the high-force and low-force groups (mean ± SD, 35.6 ± 28.2 mm; mean difference, 12.4 mm; 95% CI: −5.7, 30.6 mm; P = .289). There were no adverse effects from treatment. Follow-up measurement occurred at a mean ± SD of 4.0 ± 1.8 days (range, 2-8 days) after the treatment session, and there were no significant differences between the groups in the number of days between treatment and follow-up. There were no significant differences in NDI between groups at follow-up (mean ± SD for the low-force group, 9.7 ± 4.1; high-force group, 8.2 ± 5.0; and placebo group, 9.7 ± 5.7), accounting for baseline NDI scores.

Pressure Pain Threshold

The time-by-group interaction for summed PPT was not significant ($F_{3.2,95.1}$ = 1.41, P = .242), indicating that the type of treatment received did not have a significant effect on PPT outcomes over time (**TABLE 2**). However, summed PPT increased across all 3 time points for participants as a whole (differences between time points, P≤.02). PPTs at individual landmarks were also analyzed separately, with no significant time-by-group interaction and some improvement overall across time, though this was not consistent across all time points for all landmarks. The ICC and standard error of measurement for PPT were 0.90 (95% CI: 0.79, 0.95) and

TABLE 1 Participant Characteristics at Baseline

Characteristic	Low Force (n = 22)	High Force (n = 21)	Placebo (n = 21)
Age, y*	32.1 ± 11.4	34.4 ± 12.5	33.7 ± 11.8
Gender (female), n (%)	14 (64)	16 (76)	18 (86)
Neck Disability Index (baseline)*†	11.8 ± 4.2	11.0 ± 5.0	12.2 ± 4.0
Length of time with neck pain, n (%)			
3 to 6 mo	3 (14)	1 (5)	1 (5)
6 to 12 mo	1 (5)	4 (19)	2 (10)
Between 1 and 2 y	4 (18)	5 (24)	3 (14)
More than 2 y	14 (64)	11 (52)	15 (71)
Neck pain interference with normal work over previous 4 wk, n (%)			
Moderately	15 (68)	13 (62)	14 (67)
Quite a bit	6 (27)	8 (38)	7 (33)
Extremely	1 (5)	0 (0)	0 (0)
Presence of headache (yes), n (%)	13 (59)	11 (52)	16 (76)
Current symptom beliefs, n (%)			
Getting worse	8 (36)	7 (33)	6 (29)
Remaining static	13 (59)	10 (48)	10 (48)
Getting better	1 (5)	0 (0)	3 (14)
Had time off work due to pain (yes), n (%)	4 (18)	2 (10)	8 (38)
Had a workers' compensation claim (yes), n (%)	1 (5)	1 (5)	1 (5)
Painful spinal level identified, n (%)			
C3	2 (9)	0 (0)	1 (5)
C4	6 (27)	8 (38)	6 (29)
C5	5 (28)	7 (33)	4 (19)
C6	6 (27)	2 (10)	4 (19)
C7	3 (14)	4 (19)	5 (24)
T1	0 (0)	0 (0)	1 (5)

Abbreviations: PPT, pressure pain threshold; VAS, visual analog scale.
**Values are mean ± SD.*
†*Scored out of 50 points.*

7.35 kPa, respectively, adjacent to the spinous process; 0.85 (95% CI: 0.72, 0.94) and 4.67 kPa over the trapezius muscle; and 0.78 (95% CI: 0.53, 0.91) and 5.48 kPa over the median nerve.

Pain

There was a significant time-by-group interaction for pain ($F_{3.1,91.1}$ = 4.65, P = .004), with the high-force group reporting more pain immediately after treatment than both the low-force group (mean difference, 11.7 mm; 95% CI: 1.9, 21.5 mm; P = .014) and the placebo group (mean difference, 17.9 mm; 95% CI: 7.9, 27.9 mm; P<.001), accounting for pain at baseline (**TABLE 2**, **FIGURE 2**). Despite this increase in pain, 20 of 21 participants in the high-force group reported that they would be willing to have this treatment again if they were attending physiotherapy. Conversely, the high-force group reported pain that was less than that of the low-force group at follow-up (mean difference, 11.3 mm; 95% CI: 0.1, 22.6 mm; P = .048) but not significantly different from that of the placebo group (mean difference, 7.4 mm; 95% CI: −4.0, 18.8 mm; P = .350) (**TABLE 2**, **FIGURE 2**), accounting for pain at baseline.

Cervical ROM

There was no significant time-by-group interaction for any of the ROM measures (sagittal ROM: $F_{3.5,103.5}$ = 0.23, P = .900; rotation ROM: $F_{4,118}$ = 2.1, P = .086; total ROM: $F_{4,118}$ = 0.66, P = .623; and degrees until onset of pain in the most painful movement direction: $F_{4,114}$ = 0.25, P = .907). There were no observable differences between groups in ROM immediately after treatment or at follow-up (**TABLE 2**).

Spinal Stiffness

There was a significant time-by-group interaction for cervical spine stiffness ($F_{4,108}$ = 2.75, P = .032). At follow-up, the high-force group was less stiff at the painful spinal level as a percentage of C7 stiffness, compared to the placebo group (mean

TABLE 2 Results for Each Time Point for Each Intervention Group (Low-Force Mobilization, High-Force Mobilization, and Placebo of Detuned Laser) and Mean Differences Between Groups (Adjusted by Baseline Value)

	Low Force (n = 22)*	High Force (n = 21)*	Placebo (n = 21)*	High Force – Low Force†	High Force – Placebo†	Low Force – Placebo†
Pain VAS, mm‡						
Baseline	33.0 ± 17.2	26.6 ± 21.0	35.9 ± 24.4	−6.3 (−22.1, 9.5)	−9.3 (−25.3, 6.7)	−3.0 (−18.8, 12.9)
After Rx	27.1 ± 17.9	38.9 ± 22.2	20.9 ± 21.2	11.7 (1.9, 21.5)§	17.9 (7.9, 27.9)§	6.2 (−3.5, 16.0)
Follow-up	26.5 ± 18.6	15.2 ± 14.8	22.5 ± 20.3	−11.3 (−22.6, −0.1)§	−7.4 (−18.8, 4.0)	4.0 (−7.2, 15.1)
ROM, deg‖						
Baseline	264.5 ± 41.1	269.3 ± 36.8	258.6 ± 49.3	4.9 (−27.2, 37.0)	10.8 (−21.6, 43.2)	5.9 (−26.2, 38.0)
After Rx	265.8 ± 35.2	271.9 ± 35.2	268.7 ± 48.0	6.0 (−6.8, 18.8)	3.2 (−9.8, 16.2)	−2.9 (−15.7, 9.9)
Follow-up	275.0 ± 35.4	271.7 ± 39.1	274.1 ± 49.6	−3.4 (−19.9, 13.2)	−2.4 (−19.4, 14.6)	0.9 (−15.6, 17.5)
PPT, kPa¶						
Baseline	558.0 ± 263.5	576.6 ± 273.6	529.9 ± 225.5	18.6 (−173.1, 210.3)	46.7 (−147.2, 240.6)	28.1 (−163.6, 219.8)
After Rx	590.4 ± 267.1	637.0 ± 341.3	554.2 ± 290.8	46.6 (−31.8, 125.0)	82.8 (3.3, 162.3)	36.2 (−42.3, 114.6)
Follow-up	634.0 ± 265.7	671.3 ± 355.0	629.7 ± 357.8	37.3 (−85.1, 159.7)	41.7 (−83.8, 167.2)	4.4 (−118.1, 126.8)
Stiffness, %‡#						
Baseline	69.2 ± 22.8	74.0 ± 23.3	73.7 ± 24.0	4.8 (−13.2, 22.8)	0.3 (−17.9, 18.5)	−4.5 (−22.5, 13.5)
After Rx	81.2 ± 20.9	74.8 ± 23.0	79.4 ± 31.6	−6.4 (−19.8, 7.1)	−4.6 (−18.2, 8.9)	1.8 (−11.7, 15.2)
Follow-up	77.1 ± 17.4	68.0 ± 22.9	85.5 ± 26.0	−9.1 (−22.3, 4.2)	−17.5 (−30.9, −4.2)§	−8.5 (−21.5, 4.5)

Abbreviations: PPT, pressure pain threshold; ROM, range of motion; Rx, treatment; VAS, visual analog scale.
**Values are mean ± SD.*
†Values are adjusted mean difference (95% confidence interval). Mean differences are from Bonferroni post hoc tests following 1-way analysis of covariance, using baseline values as the covariates.
‡Statistically significant time-by-group interaction effects for this variable.
§Difference between groups was significant at the .05 level (Bonferroni adjusted).
‖Flexion, extension, and rotation (right and left), summed.
¶Sum of the measurements taken adjacent to the painful spinous process (right), mid-trapezius muscle (right), and median nerve trunk at the elbow (right).
#Instrumented stiffness measurement (slope of linear portion of force-displacement curve, N/mm) over the painful spinous process and expressed as a percentage of stiffness measured at C7 at the same time point. Percentages less than 100% indicate that the painful spinal levels were less stiff than C7.

difference, 17.5%; 95% CI: 4.2%, 30.9%; $P = .006$), but was not significantly different from the low-force group (mean difference, 9.1%; 95% CI: −4.2%, 22.3%; $P = .293$) (**TABLE 2**, **FIGURE 3**), accounting for baseline stiffness. The representative size of the difference between the high-force and placebo groups, calculated as 17.5% of the average C7 stiffness in this sample, was 1.5 N/mm. There were no significant differences between groups in spinal stiffness immediately after treatment.

DISCUSSION

To our knowledge, this is the first study to investigate the effects of differences in applied mobilization force on clinical outcomes in patients with chronic neck pain. PPT and cervical ROM following mobilization were not different between groups receiving either a high-force (90 N) or low-force

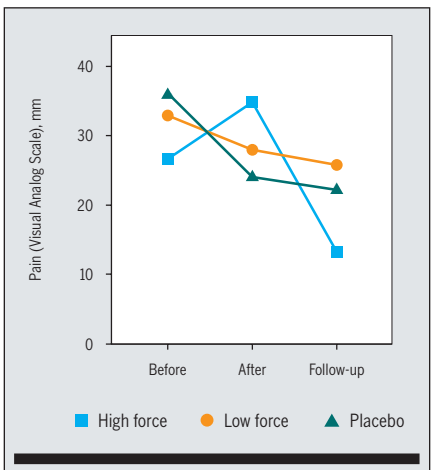

FIGURE 2. Pain measured on a 100-mm visual analog scale before and immediately after treatment (low-force [30 N] or high-force [90 N] mobilization or placebo) and at short-term follow-up.

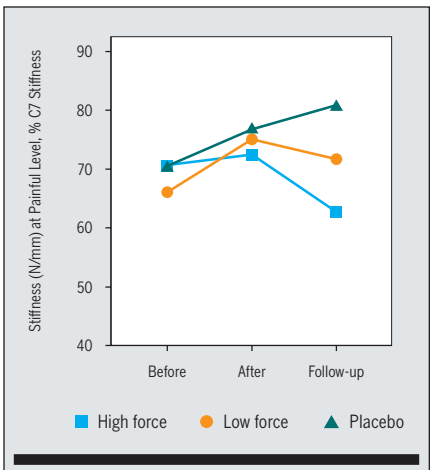

FIGURE 3. Spinal stiffness (N/mm) at the painful spinal level, normalized as a percentage of a participant's C7 spinal stiffness, measured before and immediately after treatment (low-force [30 N] or high-force [90 N] mobilization or placebo) and at short-term follow-up. Percentages less than 100% indicate that the painful spinal levels were less stiff than C7.

(30 N) mobilization (within the range of commonly applied forces by physiotherapists), or a placebo treatment. A higher mobilization force appeared to be more effective than a lower one in terms of reduced pain at a short-term follow-up approximately 4 days following treatment. However, the lower pain level in the group receiving high-force mobilization was not significantly different from the reduced pain observed in a placebo group, suggesting that patient expectation played a role in pain outcomes. A high mobilization force also significantly decreased spinal stiffness compared to a placebo at the short-term follow-up, though this decreased stiffness was not significantly different from that occurring with a low-force mobilization. Immediately after the treatment, patients who received the high-force mobilization reported increased pain and had no change in stiffness. This suggests that the effect of mobilization may not be mechanical, as an immediate change in stiffness would indicate. Alternatively, stiffness measurement may be affected by muscle contraction related to pain, as stiffness was less when pain was less. The results of this study suggest that a possible threshold of force may be necessary for reducing the symptoms of chronic neck pain using manual therapy. These results should be viewed with caution, however, as the patients participating in this study reported low disability.

Pressure Pain Threshold

There were no differences between groups in PPT following treatment in the current study. Similarly, Willett et al[71] found no difference in PPT between groups of asymptomatic subjects receiving different mobilization oscillation frequencies. In patients with whiplash, Sterling et al[64] also reported no difference in PPT between a group receiving a lateral-glide mobilization and a placebo group receiving manual contact, in which the hands of the therapist were placed on the patient without applying any mobilization force. In contrast to these findings, evidence from many previous studies indicates that PPT increases following various manual therapy techniques,[15,39,65] including cervical spine mobilization,[37] with a meta-analysis of 10 studies concluding a favorable effect on PPT from high-velocity thrust manipulations.[13] PPT generally increased over time for all groups in the current study, but did not differ by group. Together, these results might suggest that the effects of manual therapy on PPT may not be related to differences in the properties of the technique applied or a strong placebo effect from detuned laser. Despite the lack of statistical differences in PPT outcomes between groups in the current study, patients in the high-force group reported less pain at follow-up than the other groups. This might suggest that there is not a clear link between a person's perception of pain and mechanical hyperalgesia when evaluating the manual therapy parameter of force. PPT may not be a meaningful measure of a person's pain response immediately after the application of a manual technique, which itself consists of an applied "pressure" or force.

Pain

At follow-up, there was significantly less resting pain experienced by participants in the high-force group compared to the low-force group, accounting for their baseline pain values. However, pain was not significantly different between the high-force and placebo groups at follow-up. Patient expectation following the interventions might have played a role in pain responses, as all treatments were presented as genuine.[3] Explanations about the expected outcomes of treatment are known to affect patient pain responses,[5] and laser treatment is known to have a strong placebo effect.[26] Nonetheless, the significantly lower values for pain in the high-force group relative to the low-force group, together with significantly reduced spinal stiffness in the high-force group relative to the placebo group, suggests that a higher applied mobilization force may be more effective in this population of those with chronic neck pain, at least in the short term. The decreased pain at follow-up is in contrast to the significantly higher pain perceived by participants immediately after receiving high-force mobilization (**FIGURE 2**).

The point estimates for the mean differences in pain between groups surpass the minimal clinically important difference of approximately 9 to 13 mm.[6,18,34] However, the 95% CIs include some values that are less than the minimal clinically important difference, indicating that caution should be exercised when interpreting the differences clinically. A proposed hypothesis that might explain an improvement in pain several days after a treatment that itself was painful is that the treatment stimulated a descending modulation of pain, as in the phenomenon of pain being used to inhibit pain.[67] Despite an increase in resting pain immediately after treatment, participants in the high-force group reported that they were willing to receive the same treatment again if they were attending physiotherapy. However, this response could have been influenced by their perceived improvement in symptoms at the time of the follow-up session, when they were asked that question. Despite the pain reported immediately after treatment, the clinically desirable reduction of pain and stiffness at follow-up in the high-force group suggests that a higher mobilization force may be more effective for patients with chronic, nonspecific neck pain. It should be noted that the mean group changes in pain were small and may not be clinically meaningful (24 mm or less on a 100-mm VAS) (**TABLE 2**), although the largest reduction in pain was 70 mm in 1 individual.

Cervical ROM

In the current study, there were no significant changes in cervical ROM following mobilization and no differences in ROM between groups receiving either a high- or low-force mobilization. There are few previous studies reporting cervical ROM measured by a blinded assessor following the application of mobilization or ma-

nipulation. Two of these also measured cervical ROM immediately following mobilization, similar to the current study, with one reporting no significant changes in ROM (all pretest-posttest differences less than 3°)[33] and another reporting significant increases of up to approximately 10°.[66] In contrast, other studies that have reported an improvement in cervical ROM following manual therapy have applied a thoracic thrust manipulation[14] and reported changes in ROM at longer follow-up points.[19,20,38] A single treatment of mobilization, as occurred in the current study, may not be enough to demonstrate a significant change in cervical ROM. Our data support a mechanism of action that might not be related to immediate or early mechanical effects, but rather some other mechanism, for example, neurophysiological effects.[4]

Spinal Stiffness

There were no significant changes in stiffness for any group immediately after the application of treatment, but participants who received high-force mobilization were less stiff at their painful spinal level at the follow-up assessment when compared to placebo (**FIGURE 3**). Several other studies have measured stiffness in the thoracic or lumbar spine immediately following the application of various manual techniques and reported no significant changes,[1,7,21,61] though only 1 of these[21] was in symptomatic patients. This suggests that the mechanism of action of manual therapy may not be mechanical in nature but, instead, may be related to the presence of pain, as the current study found that the group that demonstrated decreased stiffness at follow-up was also the group that reported less pain. A possible explanation for our data may be that stiffness measurement may not represent an independent mechanical construct but, rather, may be a function of the pain experience and the accompanying neurophysiological effects in addition to mechanical properties of the deformed soft tissues. However, it should be noted that the established stiffness measurement protocols are designed to control for potentially pain-related phenomena such as breathing,[51] neck position,[54] and muscle contraction.[12,62]

In contrast to the current study, Fritz et al[17] found a significant decrease in stiffness in the lumbar spine immediately following a thrust manipulation in patients classified as responders, though this decrease was not maintained 3 to 4 days later. Tuttle et al[66] also reported decreased stiffness immediately following mobilization in the cervical spine, but only when stiffness was measured in specific ranges (less than 20 N) of the force-displacement curve. The differences in stiffness between groups in the current study were also small (**TABLE 2**), possibly suggesting that both levels of mobilization force had some effect or that stiffness changes were the result of multiple factors rather than solely due to the mobilization application. The sparse and conflicting evidence for spinal stiffness changes following manual therapy suggests that further research is needed, particularly to determine the relationship between spinal stiffness and pain.[53]

Limitations

The results of this study are limited to the short-term effects following the application of a single mobilization treatment to a specific sample of patients with chronic, nonspecific neck pain. The study was designed this way to investigate the effect of applied force, which is 1 property of mobilization. It is possible that the results might be different if a course of treatment is provided over several sessions, or if different properties of applied force are altered. Specifically, the velocity of applied force (mobilization versus thrust manipulation) has been shown to influence outcomes.[14] Our sample had low disability compared to other manual therapy studies[63,64] (mean ± SD NDI, 11.7 ± 4.4) (**TABLE 1**), so the results may not apply to patients with more disabling neck pain. The findings may also not relate to patients with previous neck trauma or radiculopathy, as these were excluded from the present study. Clinicians commonly tailor their mobilization parameters, modifying the magnitude of applied force based on their assessment of a patient's spinal stiffness and pain. The results might have been different if the therapist had been allowed to select a magnitude of force for each participant based on clinical judgment. Last, it should be noted that the statistically significant differences observed in this study were small and may not be clinically meaningful. Furthermore, caution is urged in concluding that there were no group differences for any statistically nonsignificant results, as type II error is a possibility. For example, the observed difference between the high-force and placebo groups in pain at follow-up and the differences between groups in spinal stiffness at follow-up appear underpowered. Therefore, strong conclusions about the possible differences between groups in these outcomes cannot be made.

CONCLUSION

This study demonstrates that a higher applied force (90 N) during a single application of cervical spine mobilization significantly reduces spinal stiffness in patients with chronic, nonspecific neck pain at a short-term follow-up (approximately 4 days). A high-force mobilization (90 N) was also more effective than a lower one (30 N) for decreasing resting pain at this short-term follow-up, though decreases in pain were not significantly different from those observed following a placebo intervention, suggesting that patient expectation might have played a role in pain response. However, the effects observed following a high-force mobilization may not all be due to a placebo effect, as the significant decrease in stiffness in this group tends to suggest a component of mechanical change. There were no observed effects of mobilization on ROM or PPT. Immediately after application of a high-force mobilization, participants reported increased pain but no significant change

in stiffness. These results suggest that a possible threshold of force is needed for reducing stiffness, and potentially pain, in patients with nonspecific neck pain.

KEY POINTS

FINDINGS: A high mobilization force (90-N mean peak force) significantly decreases spinal stiffness at a short-term follow-up of approximately 4 days after treatment, though stiffness was not reduced immediately after treatment. Also at this follow-up, pain was significantly less following a high-force (90 N) compared with a low-force (30 N) mobilization, but was not significantly different from that of a placebo treatment.

IMPLICATION: A particular threshold of force appears necessary for more effective mobilization treatment, suggesting that specific doses of mobilization should be further investigated.

CAUTION: These results are limited to patients with chronic, nonspecific neck pain and relatively low disability.

ACKNOWLEDGEMENTS: *The authors would like to acknowledge physiotherapists Dane P. Fehlberg and Bruce F. Donald for their assistance with data collection, and Zoe C. Baldwin for her assistance with participant recruitment and data entry.*

REFERENCES

1. Allison G, Edmonston S, Kiviniemi K, Lanigan H, Simonsen AV, Walcher S. Influence of standardized mobilization on the posteroanterior stiffness of the lumbar spine in asymptomatic subjects. *Physiother Res Int*. 2001;6:145-156.
2. Audette I, Dumas JP, Côté JN, De Serres SJ. Validity and between-day reliability of the cervical range of motion (CROM) device. *J Orthop Sports Phys Ther*. 2010;40:318-323. http://dx.doi.org/10.2519/jospt.2010.3180
3. Bialosky JE, Bishop MD, Cleland JA. Individual expectation: an overlooked, but pertinent, factor in the treatment of individuals experiencing musculoskeletal pain. *Phys Ther*. 2010;90:1345-1355. http://dx.doi.org/10.2522/ptj.20090306
4. Bialosky JE, Bishop MD, Price DD, Robinson ME, George SZ. The mechanisms of manual therapy in the treatment of musculoskeletal pain: a comprehensive model. *Man Ther*. 2009;14:531-538. http://dx.doi.org/10.1016/j.math.2008.09.001
5. 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. http://dx.doi.org/10.1186/1471-2474-9-19
6. Bird SB, Dickson EW. Clinically significant changes in pain along the visual analog scale. *Ann Emerg Med*. 2001;38:639-643. http://dx.doi.org/10.1067/mem.2001.118012
7. Campbell BD, Snodgrass SJ. The effects of thoracic manipulation on posteroanterior spinal stiffness. *J Orthop Sports Phys Ther*. 2010;40:685-693. http://dx.doi.org/10.2519/jospt.2010.3271
8. Chen CC, Johnson MI. An investigation into the hypoalgesic effects of high- and low-frequency transcutaneous electrical nerve stimulation (TENS) on experimentally-induced blunt pressure pain in healthy human participants. *J Pain*. 2010;11:53-61. http://dx.doi.org/10.1016/j.jpain.2009.05.008
9. Chien A, Sterling M. Sensory hypoaesthesia is a feature of chronic whiplash but not chronic idiopathic neck pain. *Man Ther*. 2010;15:48-53. http://dx.doi.org/10.1016/j.math.2009.05.012
10. Chiu TW, Wright A. To compare the effects of different rates of application of a cervical mobilisation technique on sympathetic outflow to the upper limb in normal subjects. *Man Ther*. 1996;1:198-203. http://dx.doi.org/10.1054/math.1996.0269
11. Cleland JA, Childs JD, Whitman JM. Psychometric properties of the Neck Disability Index and Numeric Pain Rating Scale in patients with mechanical neck pain. *Arch Phys Med Rehabil*. 2008;89:69-74. http://dx.doi.org/10.1016/j.apmr.2007.08.126
12. Colloca CJ, Keller TS. Active trunk extensor contributions to dynamic posteroanterior lumbar spinal stiffness. *J Manipulative Physiol Ther*. 2004;27:229-237. http://dx.doi.org/10.1016/j.jmpt.2003.11.001
13. Coronado RA, Gay CW, Bialosky JE, Carnaby GD, Bishop MD, George SZ. Changes in pain sensitivity following spinal manipulation: a systematic review and meta-analysis. *J Electromyogr Kinesiol*. 2012;22:752-767. http://dx.doi.org/10.1016/j.jelekin.2011.12.013
14. Dunning JR, Cleland JA, Waldrop MA, et al. Upper cervical and upper thoracic thrust manipulation versus nonthrust mobilization in patients with mechanical neck pain: a multicenter randomized clinical trial. *J Orthop Sports Phys Ther*. 2012;42:5-18. http://dx.doi.org/10.2519/jospt.2012.3894
15. Fernández-Carnero J, La Touche R, Ortega-Santiago R, et al. Short-term effects of dry needling of active myofascial trigger points in the masseter muscle in patients with temporomandibular disorders. *J Orofac Pain*. 2010;24:106-112.
16. Fischer AA. Pressure threshold measurement for diagnosis of myofascial pain and evaluation of treatment results. *Clin J Pain*. 1986;2:207-214. http://dx.doi.org/10.1097/00002508-198612000-00001
17. Fritz JM, Koppenhaver SL, Kawchuk GN, Teyhen DS, Hebert JJ, Childs JD. Preliminary investigation of the mechanisms underlying the effects of manipulation: exploration of a multivariate model including spinal stiffness, multifidus recruitment, and clinical findings. *Spine (Phila Pa 1976)*. 2011;36:1772-1781. http://dx.doi.org/10.1097/BRS.0b013e318216337d
18. Gallagher EJ, Liebman M, Bijur PE. Prospective validation of clinically important changes in pain severity measured on a visual analog scale. *Ann Emerg Med*. 2001;38:633-638. http://dx.doi.org/10.1067/mem.2001.118863
19. González-Iglesias J, Fernández-de-las-Peñas C, Cleland JA, Alburquerque-Sendín F, Palomeque-del-Cerro L, Méndez-Sánchez R. Inclusion of thoracic spine thrust manipulation into an electro-therapy/thermal program for the management of patients with acute mechanical neck pain: a randomized clinical trial. *Man Ther*. 2009;14:306-313. http://dx.doi.org/10.1016/j.math.2008.04.006
20. González-Iglesias J, Fernández-de-las-Peñas C, Cleland JA, del Rosario Gutiérrez-Vega M. Thoracic spine manipulation for the management of patients with neck pain: a randomized clinical trial. *J Orthop Sports Phys Ther*. 2009;39:20-27. http://dx.doi.org/10.2519/jospt.2009.2914
21. Goodsell M, Lee M, Latimer J. Short-term effects of lumbar posteroanterior mobilization in individuals with low-back pain. *J Manipulative Physiol Ther*. 2000;23:332-342.
22. Gross A, Miller J, D'Sylva J, et al. Manipulation or mobilisation for neck pain. *Cochrane Database Syst Rev*. 2010:CD004249. http://dx.doi.org/10.1002/14651858.CD004249.pub3
23. Gross AR, Haines T, Goldsmith CH, et al. Knowledge to action: a challenge for neck pain treatment. *J Orthop Sports Phys Ther*. 2009;39:351-363. http://dx.doi.org/10.2519/jospt.2009.2831
24. Gross J, Fetto J, Rosen E. *Musculoskeletal Examination*. 2nd ed. Malden, MA: Blackwell Science; 2002.
25. Hancock MJ, Maher CG, Latimer J, McAuley JH. Selecting an appropriate placebo for a trial of spinal manipulative therapy. *Aust J Physiother*. 2006;52:135-138.
26. Heussler JK, Hinchey G, Margiotta E, et al. A double blind randomised trial of low power laser treatment in rheumatoid arthritis. *Ann Rheum Dis*. 1993;52:703-706.
27. Hogg-Johnson S, van der Velde G, Carroll LJ, et al. The burden and determinants of neck pain in the general population: results of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. *Spine (Phila Pa 1976)*. 2008;33:S39-S51.
28. Hoppenfeld S. *Physical Examination of the Spine and Extremities*. New York, NY: Appleton-Century-Crofts; 1976.
29. Hurwitz EL, Carragee EJ, van der Velde G, et al.

Treatment of neck pain: noninvasive interventions: results of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. *Spine (Phila Pa 1976)*. 2008;33:S123-S152. http://dx.doi.org/10.1097/BRS.0b013e3181644b1d

30. Irnich D, Behrens N, Molzen H, et al. Randomised trial of acupuncture compared with conventional massage and "sham" laser acupuncture for treatment of chronic neck pain. *BMJ*. 2001;322:1574-1578. http://dx.doi.org/10.1136/bmj.322.7302.1574
31. Jull G. Use of high and low velocity cervical manipulative therapy procedures by Australian manipulative physiotherapists. *Aust J Physiother*. 2002;48:189-193.
32. Kanlayanaphotporn R, Chiradejnant A, Vachalathiti R. Immediate effects of the central posteroanterior mobilization technique on pain and range of motion in patients with mechanical neck pain. *Disabil Rehabil*. 2010;32:622-628. http://dx.doi.org/10.3109/09638280903204716
33. Kanlayanaphotporn R, Chiradejnant A, Vachalathiti R. The immediate effects of mobilization technique on pain and range of motion in patients presenting with unilateral neck pain: a randomized controlled trial. *Arch Phys Med Rehabil*. 2009;90:187-192. http://dx.doi.org/10.1016/j.apmr.2008.07.017
34. Kelly AM. Does the clinically significant difference in visual analog scale pain scores vary with gender, age, or cause of pain? *Acad Emerg Med*. 1998;5:1086-1090.
35. Krouwel O, Hebron C, Willett E. An investigation into the potential hypoalgesic effects of different amplitudes of PA mobilisations on the lumbar spine as measured by pressure pain thresholds (PPT). *Man Ther*. 2010;15:7-12. http://dx.doi.org/10.1016/j.math.2009.05.013
36. Latimer J, Lee M, Adams RD. The effects of high and low loading forces on measured values of lumbar stiffness. *J Manipulative Physiol Ther*. 1998;21:157-163.
37. La Touche R, Fernández-de-las-Peñas C, Fernández-Carnero J, et al. The effects of manual therapy and exercise directed at the cervical spine on pain and pressure pain sensitivity in patients with myofascial temporomandibular disorders. *J Oral Rehabil*. 2009;36:644-652. http://dx.doi.org/10.1111/j.1365-2842.2009.01980.x
38. Lau HM, Wing Chiu TT, Lam TH. The effectiveness of thoracic manipulation on patients with chronic mechanical neck pain – a randomized controlled trial. *Man Ther*. 2011;16:141-147. http://dx.doi.org/10.1016/j.math.2010.08.003
39. Lewis C, Khan A, Souvlis T, Sterling M. A randomised controlled study examining the short-term effects of Strain–Counterstrain treatment on quantitative sensory measures at digitally tender points in the low back. *Man Ther*. 2010;15:536-541. http://dx.doi.org/10.1016/j.math.2010.05.011
40. Lewis M, James M, Stokes E, et al. An economic evaluation of three physiotherapy treatments for non-specific neck disorders alongside a randomized trial. *Rheumatology (Oxford)*. 2007;46:1701-1708.
41. Magarey ME, Rebbeck T, Coughlan B, Grimmer K, Rivett DA, Refshauge K. Pre-manipulative testing of the cervical spine review, revision and new clinical guidelines. *Man Ther*. 2004;9:95-108. http://dx.doi.org/10.1016/j.math.2003.12.002
42. Maitland GD, Hengeveld E, Banks K, English K. *Maitland's Vertebral Manipulation*. 7th ed. Philadelphia, PA: Elsevier/Butterworth-Heinemann; 2005.
43. McLean S, Naish R, Reed L, Urry S, Vicenzino B. A pilot study of the manual force levels required to produce manipulation induced hypoalgesia. *Clin Biomech (Bristol, Avon)*. 2002;17:304-308.
44. Owens EF, Jr., DeVocht JW, Wilder DG, Gudavalli MR, Meeker WC. The reliability of a posterior-to-anterior spinal stiffness measuring system in a population of patients with low back pain. *J Manipulative Physiol Ther*. 2007;30:116-123. http://dx.doi.org/10.1016/j.jmpt.2006.12.006
45. Palmer ML, Epler ME. *Fundamentals of Musculoskeletal Assessment Techniques*. 2nd ed. Philadelphia, PA: Lippincott-Raven Publishers; 1998.
46. Pentelka L, Hebron C, Shapleski R, Goldshtein I. The effect of increasing sets (within one treatment session) and different set durations (between treatment sessions) of lumbar spine posteroanterior mobilisations on pressure pain thresholds. *Man Ther*. 2012;17:526-530. http://dx.doi.org/10.1016/j.math.2012.05.009
47. Potter L, McCarthy C, Oldham J. Algometer reliability in measuring pressure pain threshold over normal spinal muscles to allow quantification of anti-nociceptive treatment effects. *int J Osteopath Med*. 2006;9:113-119.
48. Reid SA, Rivett DA, Katekar MG, Callister R. Sustained natural apophyseal glides (SNAGs) are an effective treatment for cervicogenic dizziness. *Man Ther*. 2008;13:357-366. http://dx.doi.org/10.1016/j.math.2007.03.006
49. Scott D, Jull G, Sterling M. Widespread sensory hypersensitivity is a feature of chronic whiplash-associated disorder but not chronic idiopathic neck pain. *Clin J Pain*. 2005;21:175-181.
50. Shirley D. Manual therapy and tissue stiffness. In: Boyling JD, Jull G, eds. *Grieve's Modern Manual Therapy: The Vertebral Column*. 3rd ed. Edinburgh, UK: Churchill Livingstone; 2004:381-390.
51. Shirley D, Hodges PW, Eriksson AE, Gandevia SC. Spinal stiffness changes throughout the respiratory cycle. *J Appl Physiol (1985)*. 2003;95:1467-1475. http://dx.doi.org/10.1152/japplphysiol.00939.2002
52. Snodgrass SJ. *Performance of Cervical Spine Mobilisation [thesis]*. Callaghan, Australia: The University of Newcastle; 2008.
53. Snodgrass SJ, Haskins R, Rivett DA. A structured review of spinal stiffness as a kinesiological outcome of manipulation: its measurement and utility in diagnosis, prognosis and treatment decision-making. *J Electromyogr Kinesiol*. 2012;22:708-723. http://dx.doi.org/10.1016/j.jelekin.2012.04.015
54. Snodgrass SJ, Rhodes HR. Cervical spine posteroanterior stiffness differs with neck position. *J Electromyogr Kinesiol*. 2012;22:829-834. http://dx.doi.org/10.1016/j.jelekin.2012.04.014
55. Snodgrass SJ, Rivett DA, Robertson VJ. Calibration of an instrumented treatment table for measuring manual therapy forces applied to the cervical spine. *Man Ther*. 2008;13:171-179. http://dx.doi.org/10.1016/j.math.2007.04.002
56. Snodgrass SJ, Rivett DA, Robertson VJ. Manual forces applied during posterior-to-anterior spinal mobilization: a review of the evidence. *J Manipulative Physiol Ther*. 2006;29:316-329. http://dx.doi.org/10.1016/j.jmpt.2006.03.006
57. Snodgrass SJ, Rivett DA, Robertson VJ. Measuring the posteroanterior stiffness of the cervical spine. *Man Ther*. 2008;13:520-528. http://dx.doi.org/10.1016/j.math.2007.07.007
58. Snodgrass SJ, Rivett DA, Robertson VJ, Stojanovski E. A comparison of cervical spine mobilization forces applied by experienced and novice physiotherapists. *J Orthop Sports Phys Ther*. 2010;40:392-401. http://dx.doi.org/10.2519/jospt.2010.3274
59. Snodgrass SJ, Rivett DA, Robertson VJ, Stojanovski E. Forces applied to the cervical spine during posteroanterior mobilization. *J Manipulative Physiol Ther*. 2009;32:72-83. http://dx.doi.org/10.1016/j.jmpt.2008.09.012
60. Snodgrass SJ, Rivett DA, Robertson VJ, Stojanovski E. Real-time feedback improves accuracy of manually applied forces during cervical spine mobilisation. *Man Ther*. 2010;15:19-25. http://dx.doi.org/10.1016/j.math.2009.05.011
61. Stamos-Papastamos N, Petty NJ, Williams JM. Changes in bending stiffness and lumbar spine range of movement following lumbar mobilization and manipulation. *J Manipulative Physiol Ther*. 2011;34:46-53. http://dx.doi.org/10.1016/j.jmpt.2010.11.006
62. Stanton T, Kawchuk G. The effect of abdominal stabilization contractions on posteroanterior spinal stiffness. *Spine (Phila Pa 1976)*. 2008;33:694-701. http://dx.doi.org/10.1097/BRS.0b013e318166e034
63. Sterling M, Jull G, Wright A. Cervical mobilisation: concurrent effects on pain, sympathetic nervous system activity and motor activity. *Man Ther*. 2001;6:72-81. http://dx.doi.org/10.1054/math.2000.0378
64. Sterling M, Pedler A, Chan C, Puglisi M, Vuvan V, Vicenzino B. Cervical lateral glide increases nociceptive flexion reflex threshold but not pressure or thermal pain thresholds in chronic whiplash associated disorders: a pilot randomised controlled trial. *Man Ther*. 2010;15:149-153. http://dx.doi.org/10.1016/j.math.2009.09.004
65. 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. http://dx.doi.org/10.1016/j.math.2006.07.011

66. Tuttle N, Barrett R, Laakso L. Relation between changes in posteroanterior stiffness and active range of movement of the cervical spine following manual therapy treatment. *Spine (Phila Pa 1976)*. 2008;33:E673-E679. http://dx.doi.org/10.1097/BRS.0b013e31817f93f9

67. van Wijk G, Veldhuijzen DS. Perspective on diffuse noxious inhibitory controls as a model of endogenous pain modulation in clinical pain syndromes. *J Pain*. 2010;11:408-419. http://dx.doi.org/10.1016/j.jpain.2009.10.009

68. Vernon H. The Neck Disability Index: state-of-the-art, 1991-2008. *J Manipulative Physiol Ther*. 2008;31:491-502. http://dx.doi.org/10.1016/j.jmpt.2008.08.006

69. Viner A, Lee M, Adams R. Posteroanterior stiffness in the lumbosacral spine. The correlation between adjacent vertebral levels. *Spine (Phila Pa 1976)*. 1997;22:2724-2729; discussion 2729-2730.

70. Ware JE, Jr., Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care*. 1992;30:473-483.

71. Willett E, Hebron C, Krouwel O. The initial effects of different rates of lumbar mobilisations on pressure pain thresholds in asymptomatic subjects. *Man Ther*. 2010;15:173-178. http://dx.doi.org/10.1016/j.math.2009.10.005