The Effectiveness of Spinal Manipulation in Increasing Muscle Strength in Healthy Individuals: A Systematic Review and Meta-Analysis

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Abstract

Objective: The purpose of this study was to systematically review the effects of spinal manipulation on muscular strength in healthy individuals and conduct a meta-analysis to appraise the quality of evidence.

Methods: Articles were searched and retrieved from MEDLINE, EMBASE, CINAHL, Cochrane Library, PubMed, Academic Search Premier, SPORTDiscus, and AMED. Searches were conducted in September 2017 without a limit on the starting period. The Physiotherapy Evidence Database scale was used to appraise the quality of the included studies. Data from eligible articles were pooled, and meta-analyses were conducted. The quality of evidence was appraised by the Grading of Recommendations, Assessment, Development and Evaluations approach. The registration number for the review on PROSPERO is CRD42017075215.

Results: A total of 911 records were screened, and 3 randomized controlled trials were eligible to be included in this review. There was a significant pooled standardized mean difference in isometric strength (0.93, 95% confidence interval [CI], 0.17-1.68; $P = .02$) between the experimental and control groups, with a moderate level of heterogeneity.

Conclusion: This review suggests that spinal manipulative therapy augments the percentage of change in isometric strength gain among healthy participants when compared to no intervention or sham manipulation. However, the heterogeneity of pooled studies in this review suggests that the results should be interpreted with caution. (J Manipulative Physiol Ther 2019;42:148-158)

Key Indexing Terms: *Manipulation, Spinal; Muscle Strength; Spine*

Introduction

Spinal manipulation is one of the most common forms of manual therapy. Although the terms *spinal manipulation* and *spinal mobilization* are proposed to be interchangeable,[1] clinically they are not identical. Spinal manipulation differs from spinal mobilization in several ways: the spinal mobilization is a set of low-velocity, nonthrust oscillations, whereas the spinal manipulation involves a dynamic thrust to a particular spinal vertebra at a high velocity and a small amplitude impulse. In addition, spinal manipulation is delivered around the end of the physiological range of motion, and a popping sound or cracking is usually produced owing to fluid cavitation of the joint.[2-4] Overall, both refer to the use of manual mechanical force of the therapists to correct or improve the spinal impairments of patients, and their effects on instant pain relief are well documented.[5,6]

Recent research on the effectiveness of spinal manipulation therapy (SMT) has shifted the focus from pain relief to other neurophysiological effects such as sensory or motor response.[2,7] Several hypotheses have been proposed for how SMT can possibly improve motor response, including by restoring biomechanical or physiological dynamics of contiguous vertebrae, re-establishing the function of the nervous system, and promoting central facilitation.[2,4] In addition, the use of SMT could reduce trapped meniscoids, adhesions, or distortion of the spinal annulus fibrosus.[2] Because of the reduction in mechanical stress on paraspinal tissues, the inflow of sensory signals to the central nervous

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system could be consequently improved.[2,8,9] Spinal nerve roots and intervertebral foramen present with a combination of biomechanical and neural characteristics, and these characteristics could render the neural tissues vulnerable to mechanical compression by the changes in the facet joints and intervertebral disc during SMT. Therefore, if SMT is used to reduce the compression between the spinal nerve roots and intervertebral foramen, it could possibly normalize the function of dorsal roots and the ganglia. Furthermore, SMT could create persistent alterations in normal sensory input from a functional spinal unit so that the excitability of the neural cells in the spinal cord is enhanced. Consequently, the responsiveness of dorsal horn neurons to an afferent signal is magnified, resulting in the effect as central facilitation.[2,8,9]

To date, several mechanistic studies have also established and demonstrated the potential effects of using SMT to increase the muscle strength of peripheral limbs.[10-13] However, there is a lack of attempts to consolidate the findings of individual studies to quantify the effects of SMT on muscle strength within the healthy population. Therefore, this study aimed to systematically review randomized controlled trials (RCTs) comparing the effect of SMT (intervention) with sham or minimal intervention (comparisons) for isometric muscle strength in healthy individuals (participants).

Methods

Protocol

The review was conducted based on the Cochrane guidelines[14] and reported according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[15] This review was registered on PROSPERO (registration number CRD42017075215).

Eligibility Criteria

Types of Studies. The inclusion criteria of the studies were limited to RCTs or controlled clinical trials in English language only. Pilot studies, nonfull text articles, and conference abstracts were excluded. The search period had no limitation to the starting date, and it extended to the date of the search on November 3, 2017.

Population

Studies on the effects of SMT on healthy individuals could provide further ideas about the neurophysiological motor effect of the intervention, regardless of the confounding possibility of abnormal muscle activation owing to pain and pathologies.[16] Therefore, this review only included studies with healthy or asymptomatic participants in both the experimental and the control groups. Adult participants (aged from 18 to 65 years) of either sex were included. Participants with active pain or pathology in the spinal region or the tested joints were excluded. No restriction was implied to the source of participants.

Intervention. The interventions in the experimental groups of this review were restricted to studies that implemented SMT using a high-velocity, low-amplitude (HVLA) thrust only. Spinal manipulative therapy referred to manipulation in the cervical, thoracic, lumbar, and sacral regions; manipulation to peripheral joints such as the shoulder, hip, or knee was not considered as the intervention in this review. In the studies, SMT was the only intervention for the experimental groups, and studies involving co-intervention were excluded.

Comparison. No treatment, sham SMT, or low-grade mobilization in control groups were included for comparison. Low-grade mobilization refers to grade I/II mobilization according to the Maitland system; they are passive repetitive oscillations or movements without reaching the end of the physiological range.[3] In addition, these techniques have been shown to have no significant effect on muscle strength, and these techniques have commonly been employed as control interventions in previous research.[17,18]

Outcomes

The primary outcomes were muscle strength and movement torque measurements of concentric, eccentric, or isometric muscle contraction. The muscle strength was inclusive of the central muscles such as neck or back flexors and extensors or peripheral muscles because the objective of the experiments was to investigate the motor effects of SMT. The measurements were taken by the load cell, handheld dynamometer, and isokinetic dynamometer with numerical readings. Studies only measuring muscle activities by electromyography (EMG), Doppler ultrasound measuring muscle thickness or change in muscle thickness, or functional tests without muscle strength measurements were excluded.

Data Sources and Search Strategy

An electronic literature search from database inception was performed in November 2017 in the following databases: MEDLINE, EMBASE, CINAHL, Cochrane Library, PubMed, Academic Search Premier, SPORTDiscus, and AMED. As an example, the comprehensive search strategy for MEDLINE is listed in Table 1. For databases where a comprehensive search was not possible, the search strategy was modified using Boolean logic. In addition, 3 relevant journals (Fig 1) and reference lists of included studies were manually searched.

Study Selection

Two reviewers (C.N.L. and C.K.A.) screened all articles independently for eligibility. Other authors provided further

Table 1. *Search Strategy for MEDLINE*

Phase I	Phase II	Phase III
Health Condition of Interest	Interventions	Outcomes
1. Asymptomatic.mp	4. passive mobili?ation.mp	23. strength.mp
2. Healthy.mp	5. spinal mobile?ation.mp	24. force.mp
3. 1 or 2	6. manipulation.mp	25. contraction.mp
	7. spinal manipulation.mp	26. isometric.mp
	8. high-velocity low amplitude thrust.mp	27. isokinetic.mp
	9. HVLAT.mp	28. concentric.mp
	10. manual therapy.mp	29. eccentric.mp
	11. 4 or 5 or 6 or 7 or 8 or 9 or 10	30. cybex.mp
	12. 3 and 11	31. 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30
	13. spine.mp	32. 22 and 31
	14. spinal.mp	
	15. cervical.mp	
	16. thoracic.mp	
	17. lumbar.mp	
	18. lumbopelvic.mp	
	19. sacroiliac.mp	
	20. SIJ.mp	
	21. 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20	
	22. 12 and 21	

opinions about study inclusion if there were disagreements between the 2 reviewers.

Data Extraction

Data of participants' demographics, interventions, muscle strength measurements, follow-up periods, and the results of the experiments were extracted from the included articles. The data were extracted by 1 reviewer (C.N.L.) and checked by another reviewer (J.N.) for accuracy and consistency. All the authors contributed to the discussion and compromised if there were disagreements.

Quality Assessment

Critical appraisal was conducted using the Physiotherapy Evidence Database (PEDro) scale. It consists of 11 items, but item 1 is nonscored. Of the 10 points, a score of 6 or above was considered high quality and low quality was defined as a score of 5 or below.[19] In addition, the 7 criteria recommended by the Cochrane Collaboration were used to assess the risk of bias in the included studies.[20]

The overall quality of evidence for the percentage change in isometric strength was determined by the use of the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system.[21] The GRADE system considers 5 criteria, that is, risk of bias, publication bias, imprecision, inconsistency, and indirectness,[22] to rate the quality of evidence as high, moderate, low, or very low. In the GRADE approach, RCTs start as high-quality evidence. The quality of evidence is rated up or down for specific factors, and the lowest quality of evidence among the criteria is considered the overall quality of evidence.

Two reviewers (C.N.L. and J.N.) independently assessed the methodological quality risk of bias of the included studies and rated GRADE for the outcome measure in the analysis. A third reviewer (C.K.A.) resolved any disagreement in each checklist between the 2 review authors.

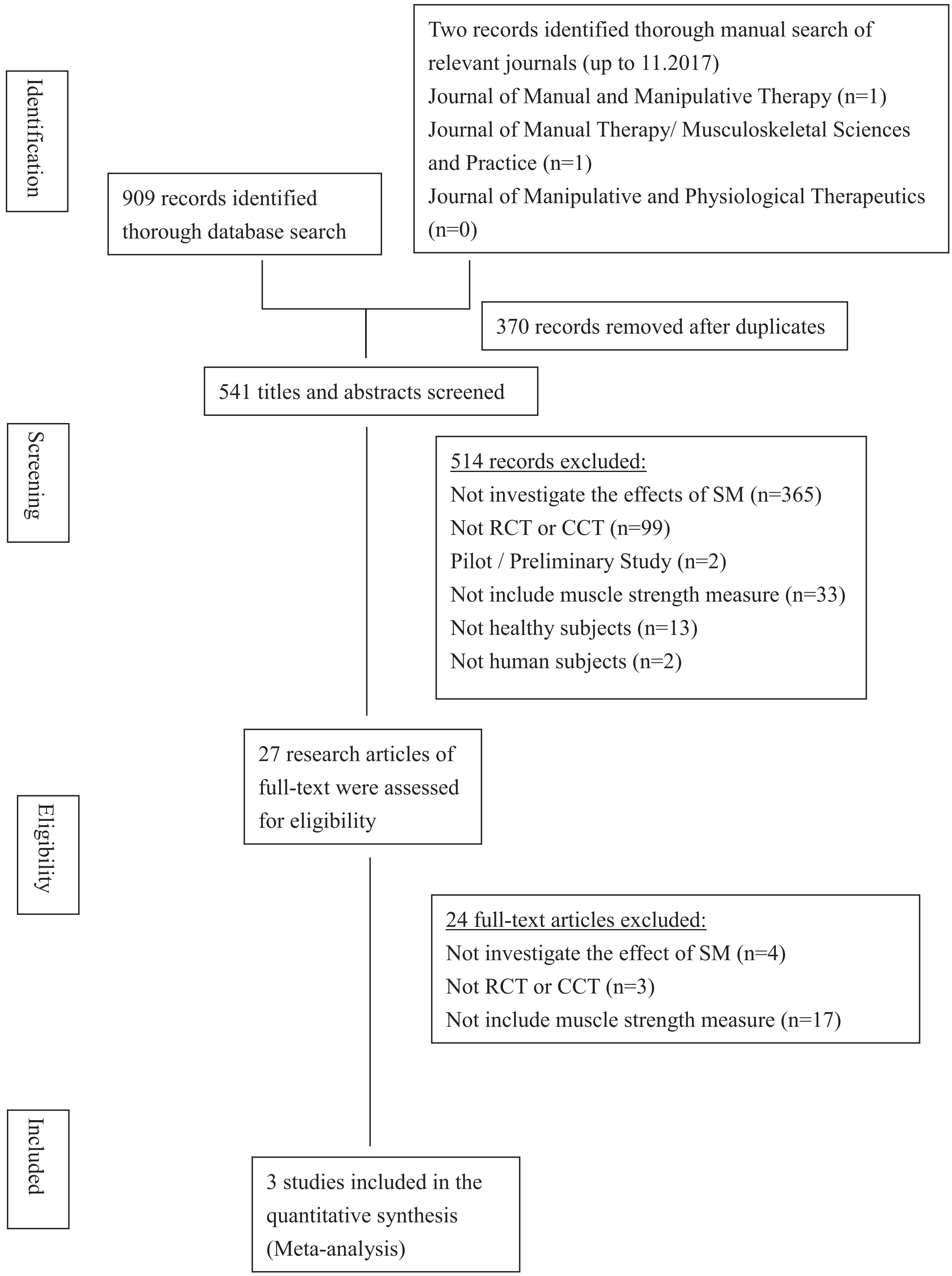

Fig 1. *The process of study selection according to the PRISMA flow diagram.* CCT, *controlled clinical trial;* PRISMA, *Preferred Reporting Items for Systematic Reviews and Meta-Analyses;* RCT, *randomized controlled trial;* SM, *spinal manipulation.*

Data Analysis

Cohen's kappa (κ) statistics was performed with PASW Statistics 18.0 for Windows (SPSS Inc, Chicago, Illinois) for the inter-rater reliability of the methodological quality scores between the 2 reviewers. This was interpreted as poor (<0.00), slight (0.00 to 0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), substantial (0.61 to 0.80), or almost perfect (0.81 to 1.0).[23]

Where appropriate and possible, the outcome measure values after the interventions of the experiments were pooled with formal meta-analytical techniques using Review Manager, version 5.3 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). The 3 included articles had a common measure as the percentage change in isometric strength after the interventions. To incorporate the variability of the outcomes into the point estimate of effect, the authors calculated the standardized mean difference (mean difference/pooled standard deviation) and its 95% confidence interval for the percentage change in isometric strength (primary outcome). A test of heterogeneity (χ^2) was performed as well.[24] The I^2 statistic was used to measure the extent of between-trial heterogeneity. Fixed-effect or random-effects models were used as appropriate and were based on our interpretation of commonality of effect size.[24] For instance, data were pooled through a random-effects model if trials differed in ways that might have plausibly affected the pooled outcome.[24]

Results

Study Selection and Exclusion

The process of selecting studies to be included in this review is illustrated in Figure 1. A total of 911 records were identified from the databases and manual journal search. Excluding 370 duplicated records, there were 541 records that underwent title and abstract screens. Of the 541 identified records, 365 were rejected because the studies did not investigate the effect of SMT as the intervention. Another 99 records were rejected because of the study design and methodology explained below. Thirty-three studies were excluded because the outcomes of the trials did not include muscle strength measurements, and 13 publications were excluded because they tested participants who were not healthy individuals. Two publications were rejected because they were pilot or preliminary studies, and 2 papers were excluded because the participants were not humans. The authors checked the full text of the remaining 27 publications; however, 24 were rejected for this review owing to similar reasons previously discussed (Appendix 1).

Study Design and Methodology. Some articles did not fulfill the inclusion criteria because the studies did not compare SMT as the experimental intervention with the control. For example, some studies compared the force or speed of SMT applied by different methods, locations, or partitioners but could not reflect the effect of SMT on muscle strength. In addition, if the intervention of the studies named SMT or spinal mobilization but did not refer to the thrusting techniques, they also failed in this criteria. Articles that were reviews, systematic reviews, observational studies, or nonrandomized trials not fulfilling the criteria of RCT or controlled clinical trial also were excluded.

Outcome Measures. As mentioned previously, to satisfy the inclusion criteria, the outcome measures of the studies should include muscle strength, which means the amount of force produced by active muscle contraction of the participants. Measurements such as EMG, muscle thickness, range of motion, joint stiffness, or functional tests were not considered as qualified for this review.

Nonhuman Subjects. Two studies recruited standing horses[25] and rats,[26] respectively, as the subjects; thus the studies were not included in this review.

Eventually, 3 publications that met all the criteria of study design, subject, intervention, and outcome measures were included for the evaluation.[16,27,28]

Study Characteristics

The 3 studies were RCTs; their characteristics of participants, interventions, and outcomes are shown in Table 2. There were 102 healthy participants included in the 3 studies. The average age of the participants was between 24 and 33.

One study employed a lumbopelvic joint manipulation as the intervention in the experimental group.[18] The other 2 studies conducted a diversified HVLA manipulation on the lumbar spine and sacroiliac joints and an anterior-posterior HVLA trust to the thoracic spine as the experimental interventions.[27,28] The control interventions were low-grade passive physiological trunk movements, sustaining a back extension posture,[18] a sham lumbosacral manipulation,[27] and a sham thoracic manipulation without getting a thrust.[28]

Cleland et al's study measured the trapezius isometric strength through a dynamometer.[28] Another study by Sanders et al recorded maximal voluntary isometric, isokinetic concentric strength of knee flexion, and extension by an isokinetic dynamometer,[27] and Grindstaff et al's experiment collected the data of isometric quadricep contracting force using a load cell and muscle activation.[16] All 3 studies reported short follow-ups, which were up to 60 minutes after the intervention.

Methodological Quality and Risk of Bias

Table 3 illustrates the PEDro scores of the selected studies. The scores ranged from 5 to 8 of 10 in which 2 were considered of low quality[16,27] and 1 was classified as high quality.[28] The agreement between the 2 reviewers was substantial (κ = 0.625, P < .001). The percentage of agreement for individual items ranged from 66.7% to

Table 2. *Characteristics of the Included Studies*

Article	Study Design	Population	Interventions	Outcome	Results
Cleland, et al[28]	Randomized controlled trial	N = 40 21 female, 19 male Age 33.1 ± 12.0 y	1. High-velocity anterior–posterior thrust on facet joints of restricted thoracic segment 2. Positioning as the experimental group, asking the participant to do a deep breath only, no manipulation	Dynamometer measurement of lower trapezius isometric strength in a supine position Outcome measure: Baseline, after intervention	Significantly greater percentage increase in lower trapezius strength in the manipulation group compared to the control group
Grindstaff, et al[16]	Randomized controlled trial	N = 41 Sex ratio was not given Age 26.6 ± 6.7 y	1. Lumbopelvic joint manipulation 2. One minute passive flexion–extension ROM movements, no touching end ranges 3. Maintaining a prone with lumbar spine extension on elbows position for 3 min	A load cell measurement of maximum isometric quadriceps force in sitting Outcome measure: Baseline, immediate after intervention, 20 min, 40 min, and 60 min	No significant time by group interaction in quadriceps MVIC force Significant difference between groups for MVIC immediately after intervention All groups demonstrated significant decreases in quadriceps force output at all time intervals after intervention.
Sanders, et al[27]	Randomized controlled single-blind crossover design	N = 21 12 men, 9 women Age 23.6 ± 3.1 y	1. Diversified HVLA manipulations of the lumbar spine or SI joints 2. A lumbar drop by a spring-loaded apparatus of the treatment table	MVCs of knee isometric extension and flexion at 60° knee flexion Isokinetic, concentric MVC of knee extension and flexion at 60°/s and 180°/s Outcome measure: Baseline, 5 min, and 20 min after intervention	No significant difference in all strength measures between spinal manipulation and sham group

HVLA, high-velocity, low-amplitude; *MVC*, maximal voluntary contraction; *MVIC*, maximum voluntary isometric contraction; *ROM*, range of motion; *SI*, sacroiliac.

Table 3. *PEDro Scores of the Selected Articles*

	PEDro Scale Criteria											
Author	1 [a]	2	3	4	5	6	7	8	9	10	11	PEDro Score
Grindstaff, et al[16]	Y	Y	N	Y	N	N	N	Y	Y	Y	N	5
Sanders, et al[27]	Y	Y	N	Y	N	N	N	Y	Y	Y	N	5
Cleland, et al[28]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8

PEDro, Physiotherapy Evidence Database.
[a] Criterion 1 was not included in PEDro score.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (Performance bias)	Blinding of outcome assessment (Detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Grindstaff et al., 2009	+	−	−	−	+	+	+
Sanders et al., 2015	+	−	−	−	+	−	+
Cleland et al., 2004	+	−	−	+	+	+	+

\+ Risk of bias low   − Risk of bias high

Fig 2. *Summary of risk of bias.*

100%. Participant and therapist blinding were commonly unsatisfied in the 3 studies.

The summary of assessing the risk of bias is shown in Figure 2. All 3 studies failed to provide adequate information on allocation concealment and blinding the intervention providers and participants; therefore, the risks of performance and detection bias were considered high.

Meta-analysis of the Intervention

Three trials that had data for measures of isometric strength were available for pooling (Fig 3). Data were pooled using a random-effects model; there was a significant pooled standardized mean difference in isometric strength (0.93, 95% confidence interval, 0.17-1.68; P = .02) between the experimental and control group, with a moderate level of heterogeneity ($I^2 = 71\%$, $\tau^2 = 0.32$, $\chi^2 = 6.96$, df = 2, P = .03).

GRADE

Table 4 presents the strength of evidence according to GRADE criteria. The overall quality of evidence was considered low.

Discussion

This systematic review has synthesized the evidence for SMT effectiveness on measures of strength in healthy individuals. The results suggest that SMT is superior to no intervention or sham manipulation in augmenting the percentage change in isometric strength gain. Compared with no intervention or sham manipulation, we found a significant effect size of 0.93, which is considered herein moderate to large in healthy individuals who received SMT. This is born out to some extent by the mean difference of 7.33% increase in isometric strength during an ad hoc analysis of the weighted mean difference in percentage change in isometric strength.

The findings from this review have elucidated, at least in part, the facilitatory effects of SMT on muscle strength rather than the analgesic effects. Previous studies that investigated injured participants were associated with several possible factors such as pain muscle inhibition and afferent dysfunction.[29-31] Thus, the differential effects of SMT on muscle strength could not be ascertained.[16,32] Previous studies have shown that SMT could improve muscle strength of patients with active pain such as back pain and neck pain,[12,33] but the underlying mechanism

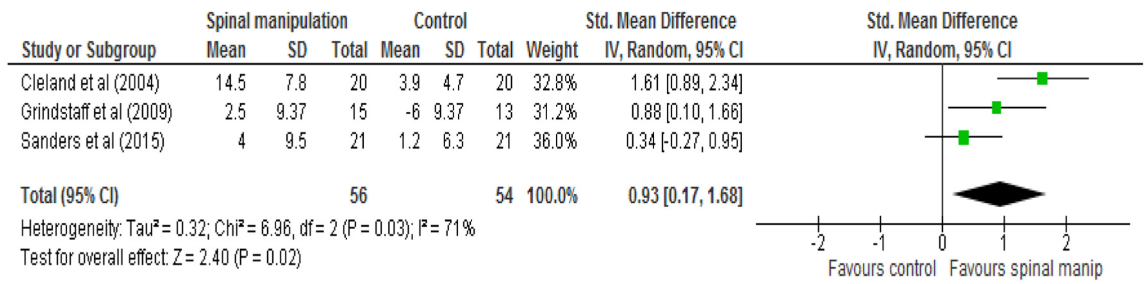

Fig 3. *Forest plot (effect size and 95% CI) of the percentage change in isometric strength of randomized controlled trials. Pooled estimate that represents effect size (standardized mean difference) and 95% CI (using a random-effects model) is indicated by diamond symbol.* CI, *confidence interval;* manip, *manipulation;* SD, *standard deviation.*

Table 4. *Overall Quality of the Evidence (Grading of Recommendations Assessment, Development and Evaluation) for Outcomes Assessed in the Meta-Analysis*

The Effect of Spinal Manipulation on Isometric Muscle Strength in Healthy Individuals								
Quality Assessment						Summary of Findings		
No of studies (Design)	Risk of bias	Publication bias	Imprecision	Inconsistency	Indirectness	No of participants (Treatment/ Control)	Pooled SMD (95% CI)	Quality of evidence
3 (2 RCTs, 1 randomized controlled single-blind crossover design)	Serious risk of bias detected	Strongly suspected	No serious imprecision	No serious inconsistency	No serious indirectness	46/56	0.93 (0.17-1.68)	⊕⊕○○ Low

CI, confidence interval; *RCT*, randomized controlled trial; *SMD*, standardized mean difference.

remained questionable. It is uncertain whether the gain in strength was due to the removal of pain inhibition[33,34] or the motor facilitation effects[2,35,36] of the SMT. Hence, the focus of healthy participants in this review could rule out the possibility of the pain inhibitory removal hypothesis and corroborate the motor facilitatory mechanism of SMT. Further studies are warranted to verify this assertion.

In this review, spinal manipulation has been defined as HVLA thrust techniques. Although previous studies have demonstrated that low-velocity end-range mobilization may also increase muscle strength,[37-39] some researchers and experiments did propose that manipulation and mobilization, thrust and nonthrust techniques, could achieve different outcomes through different mechanisms.[40,41] Nonetheless, we have chosen to focus on the effect of manipulation. More specifically, this review focused on the effect of SMT on the percentage change in isometric muscle strength. Even though previous studies have used muscle activation and EMG as outcome measures,[18,35,42] our review did not include these measurements. First, we contend that isometric muscle strength itself is the most direct surrogate of motor performance. Second, the conflicting EMG results across the literature have raised questionable doubts about the role of EMG in being able to reflect the change in isometric muscle strength after the intervention sufficiently.[43] To date, there have been pilot studies that have started to use functional tasks and muscle strength as outcome measures[44-47] to reflect the clinical relevance of the effects of SMT on the percentage change in isometric muscle strength. Unfortunately, those articles did not fulfill the inclusion criteria in this review.

Apart from the postulation that SMT restores biomechanical or physiological dynamics of the spine, re-establishes the function of the nervous system, and facilitates via a central pathway,[2,4] several plausible mechanisms for the motor facilitatory effect of SMT have been proposed and investigated. The mechanisms include increasing descending drive or modulation in afferents,[48] and the gain of the motoneuron pool by temporal and spatial summation of changing postsynaptic potentials from different spinal pathways.[35,49] Previous studies have reported a significant change in H (Hoffmann's)-reflex pathway and V (volitional)-wave in superficial EMG immediately after SMT.[13,48] The H-reflex reflects the activities of muscle spindle primary afferent fibers (Ia) and the motoneurons innervating the muscles. After the SMT, a lower recruitment threshold of motoneurons to Ia afferent input has been reported as evident with the significant decrease in H-reflex threshold, whereas the increase in V-wave after SMT indicated that there was likely to be a gain in action potential density, which was sent down from the supraspinal centers.[13,48]

The mechanism of facilitating the spinal afferent pathway after SMT appears to be convincing, as evident with the use of transcranial magnetic stimulation (TMS) to investigate the neurophysiological effects of SMT. This measurement quantifies the changes in corticospinal excitability of a targeted muscle before and after spinal manipulation in terms of motor-evoked potentials (MEPs). A previous study found that after SMT, the mean peak-to-peak MEP maximum (MEPmax) values of peripheral muscles were significantly facilitated, indicating that the specific intracortical facilitatory and inhibitory pathways were altered in a muscle-specific manner.[50] It is tempting to speculate that the aforementioned mechanism may be specific to the presence or absence of pain, or whether it is an axial or peripheral muscle. Firstly, Haavik and colleagues (2016)[51] have attempted to investigate further the effect of SMT through movement-related cortical potential amplitudes and looking into the changes in TMS input–output (TMS I/O) curves and F-wave amplitudes. Similarly, their results reported a significantly larger MEPmax for TMS I/O curves (cortical measure) after SMT. Conversely, there was no change in F-wave amplitudes (spinal measure).[51] It suggested that the facilitating responses may vary at the cortical level and the spinal level. It is conceivable that the corticospinal reaction may possibly be different in healthy individuals because the participants recruited in their study were subclinical pain participants. Interestingly, Clark et al[49] have reported that the MEPs of the spinal muscles of patients with chronic low back pain did not change after SMT. The inconsistent findings among different patient populations may be attributed, at least in part, to the presence of pain, which is known to alter brain activity[52,53] and hence the corticospinal response to SMT. The other hypothesized effects of SMT, which include sympatho-excitation[2,32,36,54] and mechanical facilitation,[28,38,39] are yet to be proven explicitly.

Limitations

There are some limitations that warrant attention in this review. First, the data suggested that there is low-quality GRADE evidence to indicate a positive effect of the SMT on isometric muscle strength compared with no intervention or sham manipulation in healthy adults. Among the 3 included studies, 1 article was of high quality, with the remaining 2 being low quality according to the results of PEDro scores (Table 3). All 3 papers failed to score in the domains of participant and therapist blinding. Similarly, the risks of selection and performance bias were commonly high among the 3 studies (Fig 2). Second, the included studies recruited participants within narrow age groups (Table 2), which results in a lack of generalizability of the results to the population of other age groups. Thirdly, the carryover effects of SMT were not adequately examined because all the studies had only short follow-up periods, up to 60 minutes after intervention.[16] Fourthly, the review included only papers published in English language, of which the chances of publication bias could not be ruled out. Last, it is conceivable that the analysis of results from either the upper or lower limb muscles may have yielded a different conclusion. However, we contend that the pooling of results from both upper and lower limbs herein is considered valid because our decision was corroborated by Haavik et al's recent study,[51] which demonstrated an increase in neurophysiological measures over the upper and lower limb muscles, suggesting an increase in cortical excitability after spinal manipulation.

Conclusion

This review suggests that SMT augments the percentage change in isometric strength gain among healthy participants compared with no intervention or sham manipulation. However, the heterogeneity of pooled studies in this review suggests that the results should be interpreted with caution. Better research methodology can be achieved with better participant allocation concealment, assessor blinding, and reporting of outcome measure variability. Future studies may consider other functional outcome measures or correlates of isometric strength or larger sample sizes with longer follow-up periods to better understand the motor facilitatory effects of SMT.

Practical Applications

- This study summarizes the use of spinal manipulation to increase peripheral muscle strength.
- Spinal manipulation could be considered an intervention for strength improvement in asymptotic individuals.
- There is low GRADE evidence to support the use of spinal manipulation to increase muscle strength.

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No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): C.N.L., J.N., C.K.A.

Design (planned the methods to generate the results): C.N.L., C.K.A., E.L.

Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): C.N.L., J.N., C.K.A., E.L.

Data collection/processing (responsible for experiments, patient management, organization, or reporting data): C.N.L., J.N., C.K.A., E.L.

Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): C.N.L., J.N., C.K.A., E.L.

Literature search (performed the literature search): C.N.L., C.K.A., E.L.

Writing (responsible for writing a substantive part of the manuscript): C.N.L., J.N., C.K.A., E.L.

Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): C.N.L., J.N., C.K.A., E.L.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jmpt.2018.10.003.

References

1. Mintken PE, Little T, DeRosa C, Little T, Smith B. A model for standardizing manipulation terminology in physical therapy practice. *J Orthop Sports Phys Ther.* 2008;38(3):1-7.
2. Pickar JG. Neurophysiological effects of spinal manipulation. *Spine J.* 2002;2(5):357-371.
3. Maitland GD. In: Hengeveld E, Banks K, eds. *Maitland's Vertebral Manipulation, Vol. 1.* 8th ed. Oxford, England/Waltham, MA: Butterworth-Heinemann; 2013.
4. Potter L, McCarthy C, Oldham J. Physiological effects of spinal manipulation: a review of proposed theories. *Phys Ther Rev.* 2005;10(3):163-170.
5. Walser RF, Meserve BB, Boucher TR. The effectiveness of thoracic spine manipulation for the management of musculoskeletal conditions: a systematic review and meta-analysis of randomized clinical trials. *J Man Manip Ther.* 2009;17(4):237-246.
6. 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(5):752-767.
7. Schmid A, Brunner F, Wright A, Bachmann LM. Paradigm shift in manual therapy? Evidence for a central nervous system component in the response to passive cervical joint mobilisation. *Man Ther.* 2008;13(5):387-396.
8. 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(21):1772-1781.
9. Haavik H, Murphy B. The role of spinal manipulation in addressing disordered sensorimotor integration and altered motor control. *J Electromyogr Kinesiol.* 2012;22(5):768-776.
10. Sterling M, Jull G, Wright A. Cervical mobilisation: concurrent effects on pain, sympathetic nervous system activity and motor activity. *Man Ther.* 2001;6(2):72-81.
11. Wang SS, Meadows J. Immediate and carryover changes of C5-6 joint mobilization on shoulder external rotator muscle strength. *J Manipulative Physiol Ther.* 2010;33(2):102-108.
12. Suter E, McMorland G, Herzog W, Bray R. Conservative lower back treatment reduces inhibition in knee-extensor muscles: a randomized controlled trial. *J Manipulative Physiol Ther.* 2000;23(2):76-80.
13. Christiansen TL, Niazi IK, Holt K, et al. The effects of a single session of spinal manipulation on strength and cortical drive in athletes. *Eur J Appl Physiol.* 2018;118(4):737-749.
14. Higgins JPT, Green S (eds). Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. The Cochrane Collaboration, 2011. Available at: http://handbook.cochrane.org. Accessed April 2, 2019.
15. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev.* 2015;4(1):1.
16. Grindstaff TL, Hertel J, Beazell JR, Magrum EM, Ingersoll CD. Effects of lumbopelvic joint manipulation on quadriceps activation and strength in healthy individuals. *Man Ther.* 2009;14(4):415-420.
17. Yerys S, Makofsky H, Byrd C, Pennachio J, Cinkay J. Effect of mobilization of the anterior hip capsule on gluteus maximus strength. *J Man Manip Ther.* 2002;10(4):218-224.
18. Grindstaff TL, Hertel J, Beazell JR, et al. Lumbopelvic joint manipulation and quadriceps activation of people with patellofemoral pain syndrome. *J Athl Train.* 2012;47(1):24-31.
19. Moseley AM, Elkins MR, Janer-Duncan L, Hush JM. The quality of reports of randomized controlled trials varies between subdisciplines of physiotherapy. *Physiother Canada.* 2014;66(1):36-43.
20. Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ.* 2011;343(7829):d5928.
21. Balshem H, Helfand M, Schünemann HJ, et al. GRADE guidelines: 3. Rating the quality of evidence. *J Clin Epidemiol.* 2011;64(4):401-406.
22. Aoyagi M, Mani R, Jayamoorthy J, Tumilty S. Determining the level of evidence for the effectiveness of spinal manipulation in upper limb pain: a systematic review and meta-analysis. *Man Ther.* 2015;20(4):515-523.
23. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977;33(1):159-174.
24. Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. *Introduction to Meta-Analysis*. Chichester, UK: John Wiley & Sons, Ltd; 2009.
25. Haussler KK, Hill AE, Puttlitz CM, McIlwraith CW. Effects of vertebral mobilization and manipulation on kinematics of the thoracolumbar region. *Am J Vet Res.* 2007;68(5):508-516.
26. Agarwal R, González-García C, Torstrick B, Guldberg RE, Salmerón-Sánchez M, García AJ. Simple coating with fibronectin fragment enhances stainless steel screw osseointegration in healthy and osteoporotic rats. *Biomaterials.* 2015;63:137-145.
27. Sanders GD, Nitz AJ, Abel MG, et al. Effects of lumbosacral manipulation on isokinetic strength of the knee extensors and flexors in healthy subjects: a randomized, controlled, single-blind crossover trial. *J Chiropr Med.* 2015;14(4):240-248.

28. Cleland J, Selleck B, Stowell T, et al. Short-term effects of thoracic manipulation on lower trapezius muscle strength. *J Man Manip Ther.* 2004;12(2):82-90.
29. Graven-Nielsen T, Lund H, Arendt-Nielsen L, Danneskiold-Samsøe B, Bliddal H. Inhibition of maximal voluntary contraction force by experimental muscle pain: a centrally mediated mechanism. *Muscle Nerve.* 2002;26(5):708-712.
30. Herzog W, Suter E. Muscle inhibition following knee injury and disease. *Sportverletz Sportschaden.* 1997;11(3):74-78.
31. Roos EM, Herzog W, Block JA, Bennell KL. Muscle weakness, afferent sensory dysfunction and exercise in knee osteoarthritis. *Nat Rev Rheumatol.* 2011;7(1):57-63.
32. Hegedus EJ, Goode A, Butler RJ, Slaven E. The neurophysiological effects of a single session of spinal joint mobilization: does the effect last? *J Man Manip Ther.* 2011;19(3):143-151.
33. Häkkinen A, Salo P, Tarvainen U, Wiren K, Ylinen J. Effect of manual therapy and stretching on neck muscle strength and mobility in chronic neck pain. *J Rehabil Med.* 2007;39(7):575-579.
34. Le Pera D, Graven-Nielsen T, Valeriani M, et al. Inhibition of motor system excitability at cortical and spinal level by tonic muscle pain. *Clin Neurophysiol.* 2001;112(9):1633-1641.
35. Dishman JD, Bulbulian R. Spinal reflex attenuation associated with spinal manipulation. *Spine (Phila Pa 1976).* 2000;25(19):2519-2525.
36. Kingston L, Claydon L, Tumilty S. The effects of spinal mobilizations on the sympathetic nervous system: a systematic review. *Man Ther.* 2014;19(4):281-287.
37. Lo CC, Chiu T, Cheung C. The effect of passive lumbar mobilization on hip flexor strength-a pilot study. *Indian J Physiother Occup Ther.* 2016;10(2):81.
38. Makofsky H, Panicker S, Abbruzzese J, et al. Immediate effect of grade IV inferior hip joint mobilization on hip abductor torque: a pilot study. *J Man Manip Ther.* 2007;15(2):103-110.
39. Liebler EJ, Tufano-Coors L, Douris P, et al. The effect of thoracic spine mobilization on lower trapezius strength testing. *J Man Manip Ther.* 2001;9(4):207-212.
40. Bolton PS, Budgell BS. Spinal manipulation and spinal mobilization influence different axial sensory beds. *Med Hypotheses.* 2005;66(2):258-262.
41. 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 Sport Phys Ther.* 2012;42(1):5-18.
42. Nougarou F, Dugas C, Deslauriers C, Pagé I, Descarreaux M. Physiological responses to spinal manipulation therapy: investigation of the relationship between electromyographic responses and peak force. *J Manipulative Physiol Ther.* 2013;36(9):557-563.
43. Arabadzhiev TI, Dimitrov VG, Dimitrov GV. The increase in surface EMG could be a misleading measure of neural adaptation during the early gains in strength. *Eur J Appl Physiol.* 2014;114(8):1645-1655.
44. Humphries KM, Ward J, Coats J, Nobert J, Amonette W, Dyess S. Immediate effects of lower cervical spine manipulation on handgrip strength and free-throw accuracy of asymptomatic basketball players: a pilot study. *J Chiropr Med.* 2013;12(3):153-159.
45. Smith DL, Dainoff MJ, Smith JP. The effect of chiropractic adjustments on movement time: a pilot study using Fitts Law. *J Manipulative Physiol Ther.* 2006;29(4):257-266.
46. Cardinale M, Boccia G, Greenway T, Evans O, Rainoldi A. The acute effects of spinal manipulation on neuromuscular function in asymptomatic individuals: a preliminary study. *Phys Ther Sport.* 2015;16(2):121-126.
47. Yuen TS, Lam PY, Lau MY, et al. Changes in lower limb strength and function following lumbar spinal mobilization. *J Manipulative Physiol Ther.* 2017;40(8):587-596.
48. Niazi IK, Türker KS, Flavel S, Kinget M, Duehr J, Haavik H. Changes in H-reflex and V-waves following spinal manipulation. *Exp Brain Res.* 2015;233(4):1165-1173.
49. Clark BC, Goss DA, Walkowski S, Hoffman RL, Ross A, Thomas JS. Neurophysiologic effects of spinal manipulation in patients with chronic low back pain. *BMC Musculoskelet Disord.* 2011;12(1):170.
50. Taylor HH, Murphy B. Altered sensorimotor integration with cervical spine manipulation. *J Manipulative Physiol Ther.* 2008;31(2):115-126.
51. Haavik H, Niazi I, Jochumsen M, Sherwin D, Flavel S, Türker K. Impact of spinal manipulation on cortical drive to upper and lower limb muscles. *Brain Sci.* 2016;7(12):2.
52. Schabrun SM, Elgueta-Cancino EL, Hodges PW. Smudging of the motor cortex is related to the severity of low back pain. *Spine (Phila Pa 1976).* 2017;42(15):1172-1178.
53. Tsao H, Danneels LA, Hodges PW. ISSLS prize winner. Smudging the motor brain in young adults with recurrent low back pain. *Spine (Phila Pa 1976).* 2011;36(21):1721-1727.
54. Mangum K, Partna L, Vavrek D. Spinal manipulation for the treatment of hypertension: a systematic qualitative literature review. *J Manipulative Physiol Ther.* 2012;35(3):235-243.