

Spinal reflex excitability changes after cervical and lumbar spinal manipulation: a comparative study

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Received 20 February 2002; accepted 19 October 2002

Abstract

Background context: Spinal manipulation (SM) is a commonly employed nonoperative treatment modality in the management of patients with neck, low back or pelvic pain. One basic physiologic response to SM is a transient decrease in motoneuron activity as assessed using the Hoffmann reflex (H-reflex) technique. Previous research from our laboratory indicates that both SM with a high-velocity, low-amplitude thrust and mobilization without thrust produced a profound but transient attenuation of motoneuronal activity of the lumbosacral spine in asymptomatic subjects. To date, effects of cervical SM procedures on the excitability cervical motoneuron pools are unknown.

Purpose: The objective of this research was to gain a more complete understanding of the physiologic effects of SM procedures on motoneuron activity, by comparing the effects of regional SM on cervical and lumbar motoneuron pool excitability.

Study design/setting: Maximal H-reflex amplitudes were recorded before and after SM in both the cervical and lumbar regions of asymptomatic subjects in two successive experimental sessions.

Patient sample: Asymptomatic, young healthy volunteers were used in this study.

Outcome measures: Changes in flexor carpi radialis and gastrocnemius H-reflex amplitudes before and after SM procedures.

Methods: H-reflexes recorded from the tibial and median nerves were evaluated before and after lumbar and cervical SM, respectively.

Results: Both Lumbar and cervical SM produced a transient but significant attenuation of motoneuron excitability. The attenuation of the tibial nerve H-reflex amplitude was proportionately greater than that of the median nerve, which occurred after cervical SM.

Conclusions: SM procedures lead to transient suppression of motoneuron excitability, as assessed by the H-reflex technique. Lumbar spine SM appears to lead to greater attenuation of motoneuron activity compared with that of the cervical region. Thus, these two distinct regions of the spine may possess different responsiveness levels to spinal manipulative therapy. © 2003 Elsevier Inc. All rights reserved.

Keywords: H-reflex; Back pain; Cervical; Lumbar; EMG; Motor neuron excitability

Introduction

Spinal manipulation (SM) is a commonly employed non-operative treatment modality in the management of patients with neck, low back or pelvic pain. Randomized clinical tri-

als of high methodological quality provide moderate evidence of short-term efficacy for SM in the treatment of acute low back pain, as well as SM combined with mobilization for chronic low back pain [1]. Rigorous randomized clinical trials are lacking with respect to efficacy of SM for mechanical neck pain [2,3], despite moderate evidence-based support for its implementation in this population [4,5]. Additional quality research endeavors using randomized clinical trials are needed to further address the efficacy of SM. However, the determination of the clinical efficacy of SM also depends on identifying a distinct population of patients who have a high probability of benefiting from SM.

FDA device/drug status: not applicable.

Nothing of value received from a commercial entity related to this research.

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This latter research criterion requires an understanding of the basic physiologic mechanisms underlying SM.

One basic physiologic response to SM is a transient decrease in motoneuron activity as assessed using the Hoffmann reflex (H-reflex) technique [6–8]. The H-reflex technique involves peripheral stimulation of the Ia afferent feedback pathway to assess the excitability of the alpha motoneuron pool. Previous research from our laboratory indicated that both SM with a high-velocity, low-amplitude (HVLA) thrust and mobilization without thrust produced a profound but transient attenuation (less than 1 minute) of motoneuronal activity of the lumbosacral spine in asymptomatic subjects [6,7]. Similarly, manipulation of the sacroiliac joint produced an attenuation of motoneuron activity for up to 15 minutes after manipulation in asymptomatic subjects [8].

In terms of a mechanism for SM-induced motoneuron inhibition, mechanical strain of the ligament-muscular system of the spine evokes reflex activation of paraspinal muscles [9,10]. The HVLA thrust is equivalent to rapidly applying a mechanical strain to the trunk and, as such, appears to be the critical factor in reflex activation of paraspinal muscles [11,12]. Reflex activation of paraspinal muscles in response to mechanical perturbations triggers a prolonged reduction of motoneuron activity [13–16]. Clinically, in a case study, reflex activation of thoracic musculature after an HVLA thrust led to a subsequent alleviation of hypertonicity in one symptomatic patient with thoracic back spasms [12]. Thus, it is plausible that motoneuron inhibition after HVLA thrust is dependent on reflex activation of velocity-dependent mechanoreceptors discharged in response to SM.

To date, effects of cervical SM procedures on the excitability cervical motoneuron pools are unknown. The cervical spine, in theory, may possess a greater responsiveness to SM than does the lumbar spine in part because the cervical spine, compared with the lumbar spine, is more densely populated by muscle spindles and zygapophysial joint mechanoreceptors, according to some reports [17–19]. Properties of synaptic transmission between Ia afferents and motoneurons and motor unit characteristics are inherently different between the cervical and lumbar spinal cords ([20]). The clinical efficacy of SM in the management of patients with neck and back pain may potentially depend on the anatomical and physiological differences between cervical and lumbosacral spinal segments.

The objective of this research was to gain a more complete understanding of the physiologic effects of SM procedures on motoneuron activity. Specifically, our knowledge of the transient attenuation of motoneuron activity at the lumbar spinal cord was extended to include the cervical spinal cord. Comparison between median nerve H-reflex excitability after a C5–C6 SM procedure and tibial nerve H-reflex excitability after an L5–S1 SM procedure was used to address the responsiveness of cervical motoneuron activity to SM.

Methods

Subjects and experimental design

The subjects were nine healthy, young volunteers recruited from a college student population. One clinician neurologically screened all subjects before the initiation of the experiments to exclude subjects with radiculopathy or peripheral neuropathy. The college's institutional review board reviewed and approved all experimental procedures.

A repeated measures experimental design was used. The median nerve H-reflex response to a C5–C6 SM procedure and the tibial nerve H-reflex response to an L5–S1 SM were measured in all subjects. The subjects received the SM procedures on different test days, in a random order, with a minimum of 48 hours between experimental sessions. One clinician, with 15 years of experience, performed the SM procedures. The SM procedures were delivered homolaterally to the H-reflex recording limb (right side) in both regions of the spine.

The measurement protocol used in each experimental session was as follows. At the beginning of the measurement protocol, the maximal M-wave response was measured. Immediately before delivering the SM procedure, 10 baseline maximal H-reflex responses were measured at a stimulation rate of 0.1 Hz. Immediately after the SM procedure, maximal H-reflex responses were measured at 10-second intervals within the first 90 seconds to determine the acute time course of postmanipulation effects on motoneuron activity. Ten maximal H-reflexes were also evoked at 5 and 10 minutes after manipulation at a stimulation rate of 0.1 Hz. At the completion of the postmanipulation H-reflex testing, the maximal M-wave response was measured.

H-reflex recording techniques

Maximal M-wave and H-reflex recording techniques were performed as per the methods of Hugon [21] for the tibial nerve. The subjects were placed prone on a treatment table with their right foot lightly secured to a plate to maintain a 90-degree angle of the foot to the tibia. The tibial nerve was stimulated in the popliteal fossa using a 1.0-ms square wave pulse delivered by a constant voltage stimulator (Grass S88; Grass Instruments, W. Warwick, RI). The cathode-stimulating electrode (10 mm self-adhesive, pregelled, Ag-AgCl) was positioned within the popliteal fossa at the optimal location for evoking an H-reflex in the gastrocnemius muscle. The optimal location for the cathode was defined as the site within the popliteal fossa at which a slightly suprathreshold stimulus for evoking an H-reflex did not evoke an M-wave response. The anode-stimulating electrode was placed 10 cm proximal to the cathode on the posterior thigh. The electromyographic (EMG) response of the gastrocnemius muscle was recorded using 10-mm bipolar self-adhesive, pregelled, surface disposable Ag-AgCl electrodes. The Braddom and Johnson [22] method of electrode configuration was used to ensure consistent placement of recording electrodes over

the gastrocnemius muscle across subjects. The EMG signal was bandpass filtered (10 Hz to 10 kHz) and amplified using an EMG amplifier system (Grass P511; Grass Instruments, W. Warwick, RI). The peak-to-peak EMG values (EMG amplitudes) of M-wave and H-reflex responses evoked in the gastrocnemius muscle were recorded with a digital oscilloscope (Tektronix TDS 420, Tektronix, Inc., Beaverton, OR).

Maximal M-wave and H-reflex recording techniques were performed as per the methods of Jabre and Stalberg [23,24] for the median nerve. The subjects were placed in a semireclined testing position on a treatment table with the right elbow slightly flexed and feet resting on foot plates. The foot plates were rotated to maintain 90-degree angles at the ankle joint. The right median nerve was stimulated using a bipolar surface electrode positioned approximately 10 cm above the cubital fossa on the medial aspect of the upper arm. The interelectrode distance was 30 mm with the cathode positioned proximally. The stimulus was a 1-ms square wave pulse delivered by a Grass S-88 stimulator in series with a stimulus isolation unit (Grass SIU5).

The determination of the optimal location for the bar electrode along the median nerve was as follows. The optimal location was the position at which a slightly supra-threshold stimulus for evoking an H-reflex response did not simultaneously evoke a large M-wave response in the flexor carpi radialis muscle. Inclusion criteria for reliable median nerve H-reflex responses were also used. Median nerve H-reflex responses had the following characteristics: 1) a latency of 14 to 17 ms; 2) increased amplitude with voluntary muscle contraction and 3) decreased amplitude with high-frequency stimulation (1 Hz). In addition, the median nerve H-reflex responses were evoked with similar latencies and morphologies from trial to trial. The morphology of the H-reflex was similar to the morphology of the M-wave. The ratio of H-reflex to M-wave (H/M) recruitment profile of the median nerve H-reflex was typical of the profile that is described for the tibial nerve H-reflex. Using these criteria, we ensured that a sufficient proportion of cervical motoneurons participated in the median nerve H-reflex response, thereby providing us with a valid tool to study the effects of a cervical manipulation procedure on motoneuron activity.

EMG recording of the evoked H-reflex response in the flexor carpi radialis muscle was collected with bipolar, surface Ag-AgCl electrodes (15 mm×20 mm). The active recording electrode was placed over the motorpoint of the flexor carpi radialis muscle, which is designated as one-third of the distance between the medial epicondyle and the radial styloid. The reference electrode was placed over the volar surface of distal forearm directly overlying the flexor tendons at the wrist. The ground electrode was then placed between the stimulating bar electrode and the active electrode (10 mm in diameter). This bipolar detection arrangement ensured similar placement of recording electrodes across subjects. The EMG signal was bandpass filtered (10 Hz to 10 kHz) and amplified using the Grass P511 EMG

system. EMG amplitudes of M-wave and H-reflex responses evoked in the flexor carpi radialis muscle were recorded with a digital oscilloscope.

H/M recruitment curve

At the beginning of the experimental session, the H/M recruitment curve was generated by increasing stimulus intensity from subthreshold to maximal in 5-volt increments. The maximal M-wave was defined as the plateau in EMG amplitude that occurred in response to three successive 5-volt increments of stimulus intensity. Stimulus intensity was then increased in 2-volt increments within the range of ± 5 volts from the apex of the H-reflex recruitment curve to determine the optimal stimulus intensity for evoking maximal H-reflexes. The optimal stimulus intensity for evoking maximal H-reflex responses in the gastrocnemius and flexor carpi radialis muscles was used throughout the protocol measurement.

Spinal manipulation procedures

The cervical and lumbar spinal manipulative procedures consisted of HVLA manipulation, as commonly performed by practitioners of manual medicine [12,25,26]. These procedures consisted of a supine rotational manipulation for the cervical region and a “side-posture” rotational manipulation for the lumbosacral region. The SM procedures were delivered unilaterally to the right side of the spine (homolateral to the H-reflex recording site). The force applied to the spine in these types of procedures has been previously reported to be delivered in approximately 200 ms [27], with linear vertebral displacements of less than 10 mm [25]. The manual force, or thrusts, to the zygapophysial joint are applied at the end of physiologic range of joint motion and extend into the so-called “paraphysiologic zone” of joint motion [28]. The paraphysiologic zone is defined as the endpoint range of motion in which a joint can be passively forced without any deleterious effects [28].

For the lumbosacral spinal manipulative procedure, the subject was in a lateral decubitus posture, with the right side up. The clinician provided a manual contact on the tissues overlying the right L5–S1 zygapophysial joint. Using the right-handed Cartesian orthogonal coordinate system of movement as a reference [29], manual tension was slightly increased by providing +Y-axis translation (axial distraction) to the spine, coupled with a + Θ Y-axis rotation force, thereby increasing the mechanical load on the soft tissues. Once tissue tension was maximized, an HVLA impulsive force was applied. The primary force vector applied to the zygapophysial joint was +Z-axis translation (posterior-anterior) with a secondary vector consisting of + Θ Y-axis rotation (left axial rotation). This L5–S1 spinal manipulative procedure has been previously described by the authors [7]. Upon completion of the lumbosacral spinal manipulative procedure, the subject was immediately returned, within 10 seconds, to the prone H-reflex testing position.

For the cervical spine manipulation procedure, the subject was in a supine, semirecumbent position. The clinician applied a right-hand contact to the paraspinal tissues overlying the right C5–C6 vertebral level. The lateral aspect of digit 2 was applied to the tissues overlying the right lamina–pedicle junction. The subject’s head was then placed in the + Θ Y plane (left head rotation), with increasing pressure applied to the soft tissues. An HVLA manual thrust was applied with a primary force vector of + Θ Y (rotation), with a secondary vector of + Θ Z rotation (lateral flexion). Upon completion of the manipulative procedure, the subject’s head was returned to the neutral position. Within 10 seconds, postmanipulation H-reflex testing began with the subject in a supine, semireclined position.

During all tibial nerve H-reflex recordings, the subjects rested prone on a treatment table with feet resting on foot plates. The foot plates were positioned to maintain 90-degree angles at the ankle joint in order to control for the effects of muscle length on H-reflex responses. Postural effects on H-reflex responses were accounted for by having the subjects rest their heads face down on the treatment table with their arms placed to the sides onto arm rests. The arms were bent at 90-degree angles at the elbow joint, whereas the head piece on the treatment table allowed for the subject to rest comfortably face down.

During all median nerve H-reflex recordings, the subjects rested in a supine position on a treatment table with the right elbow slightly flexed and feet resting on foot plates. In order to control for the confounding influence of muscle length changes on H-reflex responses, elbow supports and wrist straps were used to maintain the right arm in a slightly flexed position for the duration of the testing session. Postural effects on H-reflex responses were accounted for by using a pillow to support the subject’s head and neck in the neutral position. The neck pillow was secured to the treatment table so that the head and neck was consistently positioned, before and after cervical manipulation.

In summary, neck position, muscle lengths and postural orientation were constant during all measurement time periods, before and after spinal procedure. The subjects were also visually observed for gross changes in arousal states to include sleeping, deep breathing, and coughing. Measurements of before and after maximal M-waves during the both experimental sessions and monitoring of submaximal M-waves during H-reflex recordings ensured that changes in the stimulating and recording environments were not confounding influences on H-reflex responses.

Statistical analysis

The dependent variable was the ratio of H-reflex_{max} to M-wave_{max} (H/M_{max} ratio) evoked in the flexor carpi radialis and gastrocnemius muscles. The H/M_{max} ratio reflects the proportion of the alpha motoneuron pool recruited by Ia afferents and is used as a functional index of alpha motoneuron pool excitability. The calculations of the H/M_{max} ratios

also provided us with a standardized measurement for comparing median nerve and tibial nerve H-reflex responses.

A two-factor repeated measures analysis of variance model was used to compare the H/M_{max} ratio recovery profiles after C5–C6 SM and L5–S1 SM procedures. The Dunnett procedure for a priori contrasts was used to detect any differences between baseline values and postmanipulation time points for each SM procedure. The H/M_{max} ratios at each postmanipulation time point were also compared between L5–S1 and C5–C6 SM procedures using the baseline values as covariates.

Results

There was a transient attenuation of the tibial nerve H-reflex, with a return to baseline values by 60 seconds after the L5–S1 SM procedure (Fig. 1; $F[8,64]=21.82$; $p<.05$). The recovery of the tibial nerve H-reflex to baseline values occurred in two phases ($F[1,40]$ linear=59.46; $F[4,40]$ departure from linearity=7.76; $p<.05$). There was a rapid recovery of the tibial nerve H-reflex between 10 and 20 seconds with a more gradual recovery from 20 seconds to 50 seconds (Fig. 2). There was also an immediate attenuation of the median nerve H-reflex, with a return to baseline values by 20 seconds after the C5–C6 SM procedure (Figs. 1 and 2; $F[8,64]=6.22$; $p<.05$). Although both tibial nerve and median nerve H-reflex responses were depressed within 10 seconds of the SM procedure, the amount of H-reflex attenuation was greater after an L5–S1 SM procedure than the C5–C6 SM procedure (Fig. 2; $F[1,7]=10.32$; $p<.05$). The significant interaction between median nerve and tibial nerve H/M_{max} recovery profiles provided statistical evidence that inhibition of motoneuron activity after an SM procedure is different between cervical and lumbosacral spinal cord segments ($F[8,64]=5.62$; $p<.05$).

In addition, the amplitudes of the M-wave responses were consistent from pretesting to posttesting in both flexor

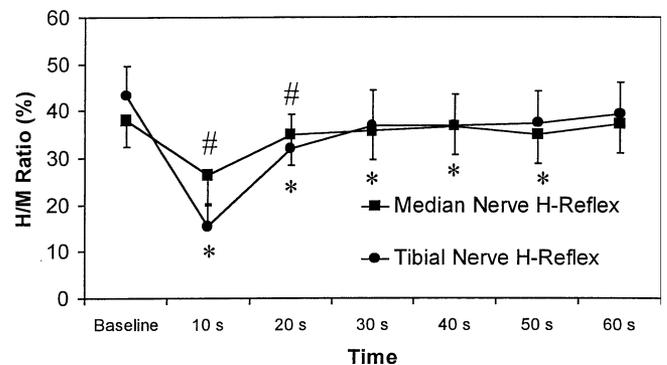


Fig. 1. Segmental effects of spinal manipulation (SM) procedures on motoneuronal activity. Changes in the H-reflex_{max} to M-wave_{max} (H/M_{max}) ratios as evoked by median nerve H-reflex stimulation after a C5–C6 SM procedure; and tibial nerve H-reflex stimulation after an L5–S1 SM procedure. Baseline values represent the premanipulation H/M_{max} ratios. Error bars are standard errors of the means. $p<.05$. # = median; * = tibial.

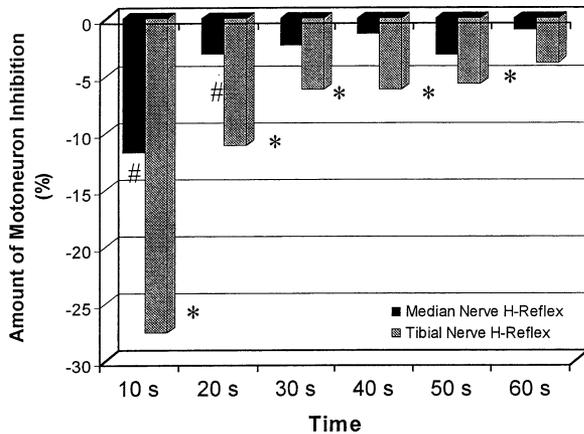


Fig. 2. Ratio of H-reflex_{max} to M-wave_{max} (H/M_{max}) recovery profiles. The data bars represent the differences between the H/M_{max} ratio at baseline and at each post-spinal manipulation (SM) time point to graphically depict the analysis of covariance and trend analysis results. These data representations clearly show the differential inhibitory effects of SM procedures on cervical and lumbosacral motoneuronal activity. $p < .05$. # = median; * = tibial.

carpi radialis and gastrocnemius muscles (Table 1). These data indicated that recording and stimulating environments were the same throughout the experimental session, before and after the SM procedure. Thus, the before and after changes in the H/M_{max} ratios reflected the physiologic effects of SM procedures on motoneuron activity.

Discussion

These data in asymptomatic subjects provide evidence that a basic physiologic response to SM is a segmental inhibition of motoneuronal activity that is transient in nature. In agreement with our previous research, an L5–S1 SM procedure exerts a transient but significant inhibition of the lumbar motoneuron activity as measured by the tibial nerve H-reflex response [6,7,30]. The new insight provided by this research was that SM-induced motoneuron inhibition was attenuated in the cervical spine compared with the lumbar spine. The magnitude and the transient nature of motoneuron inhibition were less among cervical motoneurons after a C5–C6 SM procedure than for lumbar motoneurons after an L5–S1 SM procedure.

It is important to note that because of our strict inclusion criteria, the median nerve H/M_{max} ratios collected in this investigation are in agreement with literature values for individuals with robust median nerve H/M_{max} ratios [23,24,31,32]. Consequently, the proportion of motoneurons participating in the median nerve and tibial nerve H-reflex responses were similar, that is, similar H/M_{max} ratios. Thus, statistical “floor effects” and susceptibility of motoneurons to inhibition as a function of test reflex amplitude cannot account for our data [33]. The differences in the H/M_{max} recovery profiles for cervical and lumbosacral motoneuron pools most

Table 1
Evoked M-wave responses, before and after spinal manipulation procedures

Muscles	Electromyographic amplitudes (mV)	
	Before SM procedure	After SM procedure
Flexor carpi radialis	5.9 ± 1.60	6.0 ± 1.62
Gastrocnemius	30.4 ± 11.14	30.7 ± 11.09

likely reflect anatomical and physiological differences between these two segments of the spinal cord.

When the stimulating and recording environments are identical before and after a perturbation, the H/M_{max} ratio will be a valid index of the changes in the summation of pre-synaptic and postsynaptic mechanisms on motoneuron activity resulting from the perturbation [34]. Although the H-reflex is affected by many stimuli [34,35], controlling the consistency of the stimulating and recording environments before and after a specific perturbation minimizes the contribution of extraneous factors to H-reflex measurements. The stimulating and recording environments were the same before and after manipulation, as evident by our consistent M-wave data. In addition, all of our H-reflex measurements, before and after SM, were performed with the subject in the same testing environment with respect to neck position, muscle lengths, postural orientation, and arousal state (see Methods section). As previously reported, cervical SM does not affect the amplitude of the tibial nerve H-reflex [36], and side-posture positioning does not affect the amplitude of motor potentials evoked in the gastrocnemius muscle after transcranial magnetic stimulation [37]. Thus, it is valid to conclude that the different stimulus response characteristics of the two regions of the spine occur as a consequence of HVLA manipulation.

SM-induced mechanical perturbations may initiate afferent discharges from cutaneous receptors, mechanoreceptors and free nerve endings innervating the muscles, ligaments and joints of the spine [14,16,38–40]. The role of cutaneous afferents is marginal with respect to the transient attenuation of motoneuron activity after joint manipulation [6,8]. Neuromuscular massage therapy directed at the paraspinal musculature of the lumbosacral region did not lead to a transient attenuation of motoneuron activity, as reported in a previous study [6]. The cutaneous anesthesia data of Murphy et al. [8] also indicated that effects of manipulative and mobilization procedures on motoneuron activity is likely mediated predominantly by joint and muscle afferents, rather than cutaneous afferents that may be activated by manual contact.

The cervical spine, compared with the lumbar spine, is more densely populated by muscle spindles, Golgi tendon organs, zygapophysial joint receptors and III and IV afferents innervating the surrounding spinal tissue [17–19,38,41–46]. HVLA thrusts applied to the cervical spine, theoretically then, should evoke a stronger summated afferent volley from mechanoreceptors as compared with a similar SM

procedure applied to the less dense afferent innervated lumbar spine. Clearly, the current data are inconsistent with this supposition.

Although mechanoreceptor density may not explain our data, organizational differences in receptor populations as a function of spinal level have been documented. Muscle spindle complexes within the neck and cervical paraspinal musculature include paired, parallel and tandem configurations, and are linked in chainlike arrays [41,45,46]. These muscle spindle complexes are often structurally associated with Golgi tendon organs and joint receptors to form complexes of neck receptors (cf [47,48]). The structural coupling of different receptor populations may allow for increased modulation of sensory input from mechanoreceptors innervating the muscles, ligaments and joints of the cervical spine compared with the lumbar spine [46–48]. The increased modulation of the summated sensory signals may increase the signal-to-noise ratio for processing afferent feedback evoked by a cervical SM procedure compared with a lumbosacral SM procedure. Consequently, the stability of motoneuron pool gain will be better regulated, that is, less affected by perturbations, in the cervical spinal cord compared with the lumbar spinal cord. In addition, mechanical thresholds for III and IV afferents are higher in the cervical spine than in the lumbar spine [40,49,50].

In the cervical spinal cord, the increased regulation of sensory feedback processes and the resultant increased stability of the input-output properties of the motoneuron pool may be related to the importance of neck proprioception to postural control and whole-body movement coordination [47,49,51,52]. Specifically, the convergence between descending tracts and the population of afferents innervating the cervical spine is more integrated to account for the complex array of neck muscles that need to control head movements during postural, locomotive and voluntary movements [46,53–61]. The paucity of monosynaptic reflexes in the dorsal neck muscles of the cat support this notion of an integrative proprioceptive mechanism involving the neck musculature and the cervical spine [54,61–65], whereas the stronger presence of disynaptic and monosynaptic reflexes in the lumbosacral paraspinal muscles and hindlimb muscle systems of the cat suggest that there are segmental differences in the central processing of proprioceptive information [66–68].

In summary, these data indicate that the central processing of afferent information appears to be distinctly different between the cervical and lumbosacral spinal cord [19,46,47,49]. The stronger modulation of afferent information by the cervical spine compared with the lumbosacral spine may account for our findings, in which the magnitude and the transient nature of motoneuron inhibition were less among cervical motoneurons after a C5–C6 SM procedure than for lumbar motoneurons after an L5–S1 SM procedure. In other words, the processing of sensorimotor information is more refined in the cervical spinal cord compared with the lumbosacral spinal cord, thereby better maintaining the stability

of the input-output properties of cervical motoneuron pools to various perturbations.

Inherent differences in the circuitry of the cervical and lumbar spinal cords may also offer some explanation as to the differential effects of SM on motoneuron activity in these two spinal segments. The transient nature of SM-induced inhibition of motoneurons may involve aftereffects. Aftereffects refer to changes in sensory discharge rates, predominantly in Ia afferents, that persist after mechanical stimulation of joints or soft tissue structures [69]. The time course of aftereffects is from a standard of 2 seconds up to 400 seconds with maximum effects persisting for 50 seconds [69,70]. Spinal manipulativelike loads and mechanical stimulation of the facet joints and supraspinous ligaments produce aftereffects in muscle spindles and Group III and IV afferents innervating the lumbar spine [13,71]. There is also sufficient evidence to suggest heteronymous inhibition of motoneurons by altering Ia afferent discharge rates from postural, synergistic and antagonistic muscles [72–77]. The transient effects of SM on motoneuron activity of peripheral muscles occur with a time course similar to other heteronymous aftereffects reported in the literature [72,78,79].

With respect to aftereffects, the distribution of monosynaptic and heteronymous Ia synapses are more restricted in the cervical spinal cord than in the lumbosacral spinal cord [45,80–82]. The efficacy of synaptic transmission between Ia afferents and alpha motoneurons may also be reduced in the cervical spinal cord compared with the lumbar spinal cord as evident by the postactivation depression and monosynaptic reflex data [30]. There are greater subdivisions of motoneuron pools in the cervical spinal cord than in the lumbosacral spinal cord; however, the distribution of motoneurons within a single motoneuron pool is more diffuse, allowing for a greater overlap of motoneuron pools [83,84]. Cervical motoneurons compared with lumbosacral motoneurons have more elaborate and highly organized dendritic tree patterns [83]. Gamma motoneuron content is greater in the cervical spine than in the lumbar spine [85].

In summary, these inherent differences in circuitry of the cervical cord may reflect the need for central regulation of motoneuron gain among concurrently active neck muscles to precisely control head movements [83,86–89]. Thus, physiologic differences in the modulation of motoneuron gain, properties of synaptic transmission between Ia afferents and motoneurons and motor unit characteristics between these two regions of the spine may make the cervical spinal cord less susceptible to motoneuron inhibition after an SM procedure than the lumbosacral spinal cord.

Regardless of the proposed physiologic mechanism responsible for our data, it is clear that these data corroborate previous reports of attenuation of alpha motoneuron pool excitability as a consequence of SM procedures [6–8,30]. Convergence of paraspinal tissue afferents on the motoneuron pool of the cervical (median) and lumbar (tibial) regions is likely, but the authors do not imply that this is evident. We have assumed that convergence occurs based on inner-

vation levels of the nerve-muscle combinations used in the current study. However, we cannot support this hypothesis based on the current data.

The subjects who participated in this study were relatively young, healthy individuals free from neck or back pain. Clearly, these data cannot be extended to offer implications to the spine pain population. Likewise, the possible clinical consequence of attenuation of motoneuron pool excitability is not known. Further research of this type in the patient population is needed to determine possible clinical ramifications, if any.

In conclusion, this is the first report, to the authors' knowledge, to demonstrate attenuation of cervical motoneuron pool excitability after cervical SM procedures. More importantly, the cervical spine response to SM appears to be of a lesser magnitude compared with the lumbar spine. Future studies are needed to determine if this difference in the stimulus-response characteristics of the two regions of the spine are of clinical significance. Likewise, further mechanistic studies are needed to determine if the inhibitory effects of SM on the motoneuron pool are mediated through presynaptic inhibition of Ia fibers in the dorsal horn, or if changes in the segmental and/or descending pathways (central processes) mediating postsynaptic inhibition of motoneurons occur as a consequence of SM. An understanding of the influence of SM on presynaptic and postsynaptic processes is important to identify pathophysiological abnormalities that may be corrected by spinal manipulative therapy.

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Twenty-Five Years Ago in Spine . . .

In 1978, William Kirkaldy-Willis and three coauthors published their observations on the anatomic pathology of lumbar spondylosis and stenosis, from which they developed theories of pathogenesis [1]. The work included spectacular color photographs, which were representative of a larger series the authors

made available for teaching. Their material was obtained from 50 autopsy specimens and 161 operations. They described pathologic changes in the facet joints, age-related changes in the nucleus, annular tears, internal disc disruption and disc resorption. They applied their observations of pathological changes to Farfan's model of the three-joint complex [2] and hypothesized how changes in one segment led to changes in adjacent segments.

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