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ORIGINAL ARTICLES

Neurophysiologic Response to Intraoperative Lumbosacral Spinal Manipulation

Christopher J. Colloca, DC,[a,b,f] Tony S. Keller, PhD,[c] Robert Gunzburg, MD, PhD,[d] Katelijne Vandeputte, MD,[e] and Arlan W. Fuhr, DC[a,f]

ABSTRACT

Background: Although the mechanisms of spinal manipulation are poorly understood, the clinical effects are thought to be related to mechanical, neurophysiologic, and reflexogenic processes. Animal studies have identified mechanosensitive afferents in animals, and clinical studies in human beings have measured neuromuscular responses to spinal manipulation. Few, if any, studies have identified the basic neurophysiologic mechanisms of spinal manipulation in human beings or animals.

Objectives: The purpose of this clinical investigation was to determine the feasibility of obtaining intraoperative neurophysiologic recordings and to quantify mixed-nerve root action potentials in response to lumbosacral spinal manipulation in a human subject undergoing lumbar spinal surgery.

Methods: An L4-L5 laminectomy was performed in a 62-year-old man. Short-duration (<0.1 ms) mechanical force, manually assisted spinal manipulative thrusts (150 N) were delivered to the lumbosacral spine with an Activator II Adjusting Instrument. With the spine exposed, spinal manipulative thrusts were delivered internally to the L5 mammillary proccess, L5-S1 joint, and the sacral base with various force vectors. This protocol was repeated by contacting the skin overlying respective anatomic landmarks. Mixed-nerve root recordings were obtained from gas-sterilized platinum bipolar hooked electrodes attached to the S1 nerve root at the level of the dorsal root ganglion during the spinal manipulative thrusts and during a 30-second baseline period during which no spinal manipulative thrusts were applied.

Results: During the active trials, mixed-nerve root action potentials were observed in response to both internal and external spinal manipulative thrusts. Differences in the amplitude and discharge frequency were noted in response to varying segmental contact points and force vectors, and similarities were noted for internally and externally applied spinal manipulative thrusts. Amplitudes of mixed-nerve root action potentials ranged from 200 to 2600 mV for internal thrusts and 800 to 3500 mV for external thrusts.

Conclusions: Monitoring mixed-nerve root discharges in response to spinal manipulative thrusts in vivo in human subjects undergoing lumbar surgery is feasible. Neurophysiologic responses appeared sensitive to the contact point and applied force vector of the spinal manipulative thrust. Further study of the neurophysiologic mechanisms of spinal manipulation in humans and animals is needed to more precisely identify the mechanisms and neural pathways involved. (J Manipulative Physiol Ther 2000;23:447-57)

Key Indexing Terms: Chiropractic; Low Back Pain; Lumbar Spine; Manipulation; Mechanoreception; Nerve Root; Neurophysiology

INTRODUCTION

Musculoskeletal disorders including low back pain (LBP) present a tremendous burden to society. LBP is the second most frequent symptomatic reason for patient visits to primary care physicians, second only to the common cold.[1] The National Center for Health Statistics in the United States reported that 14.3% of new patient visits to physicians are for LBP symptoms, totalling 12,900,000 visits for chronic LBP and 4,114,000 visits for low back symptoms.[2] LBP is the leading cause of disability in people younger than age 45 and the second leading cause of industrial absenteeism.[3] LBP disables 2.4 million Americans at any given time, one half of whom are chronically disabled.[4] From 1984 to 1990, estimated direct costs of spinal disorders increased from $13 billion to $23 billion,[1] and combined with indirect costs, figures have estimated that LBP represents a cost of more than $50 billion annually to the United States. These statistics and similar international epidemiologic studies have demonstrated the enormous societal impact of spinal disorders. Back pain has been called a "20th century health care disaster."[5]

Most health care for musculoskeletal disorders, including LBP, is provided for by conservative care.[6] Spinal manipulative therapy (SMT) is a conservative treatment that has been

[a]Postdoctoral and Related Professional Education Department Faculty, Logan College of Chiropractic, St. Louis, Mo.
[b]Private practice of chiropractic, Phoenix, Ariz.
[c]Professor, Department of Mechanical Engineering, University of Vermont, Musculoskeletal Research Laboratory, Burlington, Vt.
[d]Senior Consultant, Department of Orthopaedics, Centennial Clinic, Antwerpen, Belgium.
[e]Department of Orthopaedics, Centennial Clinic, Antwerpen, Belgium.
[f]National Institute of Chiropractic Research, Phoenix, Ariz.
Research supported by grants from the National Institute of Chiropractic Research, National Chiropractic Mutual Insurance Company, and Logan College of Chiropractic.
Submit reprint requests to: Dr Christopher J. Colloca, State of the Art Chiropractic Center, P.C., 11011 S 48th St, Suite 205, Phoenix, AZ 85044; *DrC100@aol.com*.
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investigated for its effectiveness in the treatment of LBP in randomized controlled trials of patients with acute, subacute, and chronic LBP.[7-10] Estimates have indicated that approximately 96% of SMT is performed by chiropractors.[11] As federal and private sector funding for chiropractic services has increased in recent years,[11,12] investigations into the proposed effectiveness and mechanisms of spinal manipulation have drawn attention.

Although the mechanisms of SMT remain poorly understood, the beneficial clinical effects of SMT are thought to be related to mechanical, neurophysiologic, and reflexogenic mechanisms.[13] Mechanical models have evolved with the theory that SMT produces realignment and improved function of misaligned and dysfunctional functional spinal units.[14] Recent evidence has demonstrated that significant functional spinal unit movements are produced by SMT in selected treatments applied to animal models[15,16] and in human studies.[17,18] Neurophysiologic models theorize that SMT may also stimulate or modulate the somatosensory system and subsequently may evoke neuromuscular reflexes.[13,19-21] Such mechanical and neurophysiologic studies suggest that joint manipulation may have both direct and indirect clinical benefits.

Recognizing the enormous impact of LBP to health care, researchers have investigated the role of somatic structures as a source of LBP. In recent years, neurophysiologic and neuroanatomic investigations have been conducted to identify and characterize somatosensory units located within the tissues of the lumbar spine to clarify their role in LBP. Devices such as glass rods, metal probes, nylon threads, and electrical impulses have been used to mechanically stimulate somatic structures and afferent units.[22-25] Mechanosensitive and nociceptive afferents have been identified in the lumbar intervertebral disks,[26-29] zygapophyseal joints,[25,30-32] spinal ligaments,[22,33-35] and the paraspinal musculature[36,37] in both animal and human studies. This research and that of others[38] have identified these tissues as probable sources of LBP and somatic referred pain.[36,39-41] Spinal nerve roots and dorsal root ganglia have also been shown to be the source of radicular pain.[42,43] The beneficial effects of SMT have been thought to be associated with mechanosensitive afferent stimulation and presynaptic inhibition of nociceptive afferent transmission in the modulation of pain,[44,45] inhibition of hypertonic muscles,[46] and improvement of functional ability.[11,47,48]

Although recent research has begun to investigate the electromyographic responses to spinal manipulation,[13,49-52] little is known about the sources of reflexogenic stimulation derived from SMT. In addition, few investigations of the neurophysiologic and biomechanic effects of SMT have been performed to date. The purpose of this study, therefore, was to determine the feasibility of obtaining intraoperative spinal nerve root neurophysiologic recordings in response to SMT stimulation of somatic structures in a human subject undergoing lumbar spinal surgery. A second objective was to determine if a short-duration, mechanical stimulation delivered in lumbar SMT by the mechanical force, manually assisted means was associated with mixed nerve root responses in the S1 nerve root and if such responses depended on contact point and applied vector. To derive a testable model in which SMT could be investigated in human subjects, SMT was delivered internally by directly contacting vertebral segments and externally by contacting the skin overlying respective anatomic points.

MATERIALS AND METHODS

Case History

A 62-year-old man underwent orthopaedic consult in June 1998, 2 years after previous lumbar surgery. Although the previous records were not available, it is most likely he had undergone L4 discectomy. The patient had persistent right lower extremity pain in an L4 and L5 dermatomal distribution that was progressively worsening. Reproduction of symptomatology was confirmed with right straight leg raise testing below 60 degrees, and a myelographic examination confirmed right foraminal stenosis at L4-L5 and L5-S1.

Surgical lumbar decompression was the necessary intervention. The surgeons advised the patient about the surgical risks, including blood loss, postoperative spinal infection, ischemic optic neuropathy, bleeding, persistent pain, paralysis, weakness, and numbness, which the patient acknowledged he understood. Consent was obtained for the surgery, and neurophysiologic assessments were conducted. The procedures used were in accordance with the standards of the hospital's ethical committee on human experimentation, in accordance with the Helsinki Declaration of 1975.

Surgical Procedure

The patient was brought to the operating room (Centennial Clinic, Antwerpen, Belgium), and general endotracheal anesthesia was induced. He was placed prone on a frame, and his low back was prepared and draped in a normal aseptic fashion. An incision was made over L3-S2 in the mid-line and brought through the subcutaneous tissue. The fascia was incised, and the musculature was carefully dissected on the left side. Self-retaining retractors were set in place, and manual suction was performed within the incised area.

An osteotomy of the L4 spinous process was conducted. Flavectomy and partial laminarthrectomy were performed at L4-L5 and L5-S1, with decompression performed on the right side only. Inspection of the epidural space indicated that the L4-L5 and L5-S1 intervertebral disks were not ruptured. After the decompression, the L4, L5, and S1 nerve root sleeves were clearly identified and free of all compression. The facet integrity of the facet joints was respected, despite the partial laminarthrectomy.

Neurophysiologic Assessment Protocol

Ten minutes were allocated to perform the neurophysiologic protocol, including set-up and testing. The S1 nerve root was chosen as the site for direct mixed-nerve root action potential recordings because this level was asymptomatic and less likely to exhibit spontaneous discharge from chronic nerve root compression.

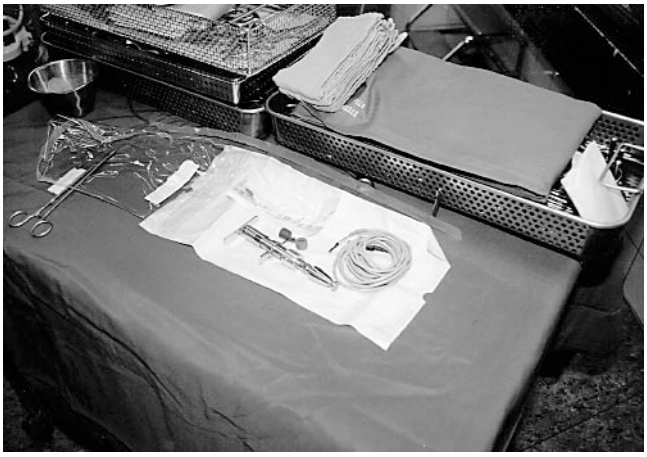

Fig 1. *Photograph of the Activator II Adjusting Instrument (Activator Methods, Inc), neoprene tips, platinum electrodes, and associated lead wires in their gas-sterilized packaging before the neurophysiologic experiments. The instrument was used to deliver the mechanical stimulus in the form of a single, short-duration (<0.1 ms) manipulative thrust (peak dynamic force = 150 N) to the lumbar spinal structures.*

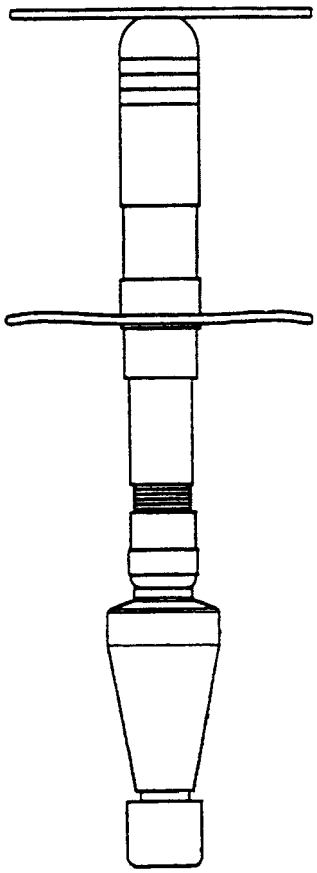

Fig 2. *Schematic of the Activator II Adjusting Instrument. The AAI II is a moving stylus-type mechanical instrument powered by the fixed potential energy of an internal spring that propels a 16-gm hammer into a 46-gm stylus. The spring is compressed manually by squeezing a sliding handle located on the shank of the instrument and at a predetermined point is activated, propelling the hammer into the stylus. An 80-durometer neoprene tip is attached to the end of the stylus that reduces the impulse force shock delivered to the spine slightly when the instrument is activated.*

Gas-sterilized platinum bipolar electrodes were shaped in the form of a hook and carefully placed directly under the right dorsal root ganglia of the S1 nerve root. The electrodes were connected to a shielded cable that was fastened to the surgical draping by clips. Careful inspection ensured that the electrodes did not come in contact with surrounding tissue. Suction was used throughout the experiment to keep the area free of excess blood and interstitial fluids. Mixed-nerve root recordings were obtained for a 30-second baseline. Baseline recordings were followed by spinal manipulative thrusts delivered by a gas-sterilized Activator II Adjusting Instrument (AAI II, Activator Methods, Inc, Phoenix, Ariz; Figs 1 and 2). Spinal manipulative thrusts were performed at various force vectors, segmental contact points, and spinal levels. Unfiltered mixed-nerve root action potentials were differentially amplified (× 1000) and recorded at 4096 Hz on a portable computer equipped with a 16-bit data acquisition system (Biopac Systems MP100, Goleta, Calif). A band stop Infinite Impulse Response (IIR) digital filter was applied to each wave form to eliminate 60-cycle noise. The IIR filter settings were 50.0 Hz and Q = 5.0.

Mechanical Stimulation of the Somatic Structures

An initial 60-second trial was conducted, during which time various internal and external thrusts and contact points (right and left sacral base, right and left L5 mammillary processes, and right and left L5-S1 zygapophyseal joints) were made to identify the presence of mixed-nerve action potential responses to mechanical stimulation. After this initial testing of the equipment and proposed protocol, nerve root recordings were made during two 30-second trials.

During the first 30-second trial, baseline recordings were made wherein the AAI II was gently set on the right L5 mammillary process, and no thrusts were delivered. During the second 30-second trial, 18 spinal manipulative thrusts were performed internally by directly contacting the right L5 mammillary processes (4 thrusts, anterior vector), L5-S1 superior zygapophyseal joint (2 thrusts, anterior-superior vector), and the right (6 thrusts, anterior-superior vector) and left (6 thrusts, anterior-superior vector) sides of the sacral base adjacent to S1. The AAI II delivers a single, short-duration (<0.1 ms) thrust with a peak force magnitude of approximately 150 N (Fig 3).[53] The preload was approximately 20 to 30 N, as routinely used in clinical (chiropractic) practice. At each of the levels (L5 and sacrum), thrusts were directed with anterior, anterior-superior, and anterior-inferior vectors (lines of drive) with the electrode in place (Fig 4).

To measure the mixed-nerve root response of external spinal manipulative thrusts delivered in a manner consistent with normal clinical chiropractic practice, 12 external spinal manipulative thrusts were applied to the spine with the AAI II by contacting the skin overlying the previously identified anatomic levels with similar force vectors (Figs 5 and 6).

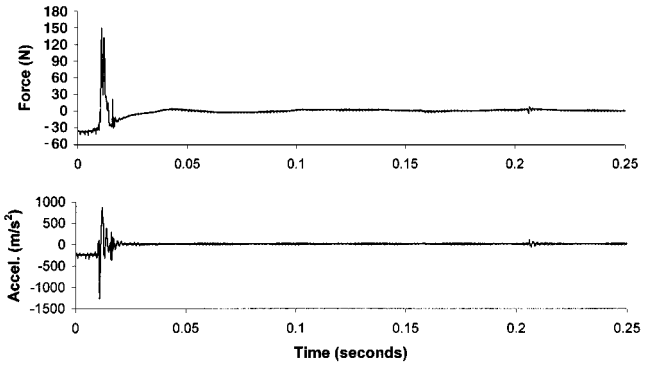

Fig 3. *Load and acceleration characteristics of a typical SMT delivered by the AAI II. Note that the force-time history produced by the AAI II is associated with a short duration (<1 ms), high loading rate, and impulsive force signal.*

Fig 4. *Photograph of the experimental set-up showing the placement of the electrodes and AAI II inside of the surgical incision for the internal SMT trials.*

Recordings were obtained for each external thrust with a 3-second time window for data acquisition. A total of 3 external spinal manipulative thrusts were delivered in an anterior vector to the skin overlying the right L5 level (to simulate the internal mammillary contact), 3 external thrusts were delivered in an anterior-superior vector to the skin overlying the right L5 level (to simulate the internal zygapophyseal joint contact), and 3 thrusts were delivered to each side of the sacral base in an anterior-inferior vector (to simulate the internal sacral base contact).

After this protocol, the electrodes were removed from the nerve root, the area was inspected, a sponge count was conducted, and copious irrigation was performed. The muscle was closed over a suction drain with 0-Vicryl (Johnson & Johnson, New Brunswick, NJ), subcutaneous tissue was sutured with 3-0 Vicryl, and the skin was sutured with 4-0 Monocryl (Johnson & Johnson) in a subcuticular fashion. A dressing was applied, and the patient was extubated and brought to the recovery room. Estimated blood loss was approximately 100 cc for the entire surgical procedure.

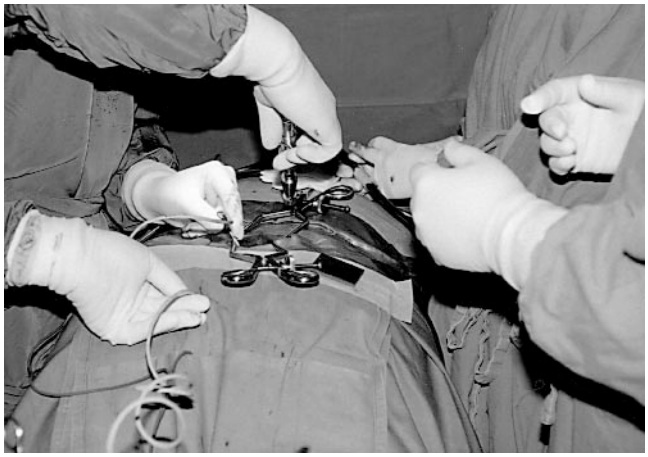

Fig 5. *Photograph illustrating the experimental set-up for external spinal manipulative thrusts during thrusts applied on the skin overlying L5 and S1 somatic structures.*

Two days after surgery, the drain was removed, and the patient ambulated without lower extremity pain. Nine days after surgery, the sutures were removed. Three weeks after surgery he asked if he could resume sports activities because his leg pain had completely resolved.

RESULTS

First 60-Second Recordings

During the first 60-second trial, no action potentials were observed in response to 3 consecutive internal spinal manipulative thrusts applied with an anterior vector to the L5 mammillary process by the AAI II. This prompted suction, adjustment, and resecuring of the electrodes around the nerve root.

Baseline Recordings

During the 30-second baseline trial, no spontaneous activity was observed in the right S1 nerve root, despite the placement of the AAI II internally with its neoprene tip in contact with the right L5 mammillary process (Fig 7). No spinal manipulative thrusts were delivered during this trial. Fig 7 provides the raw data, with the IIR filtered response superimposed on the raw data, whereas the rest of the figures have been IIR filtered.

Active Recordings During Internal Spinal Manipulative Thrusts

During the next 30-second trial, mixed-nerve root action potentials were observed in response to internal spinal manipulative thrusts. Differences in the amplitude and discharge frequency were recorded in response to varying segmental contact points and force vectors used in the delivery of the spinal manipulative thrusts. Notably, during the 4 anterior-directed spinal manipulative thrusts performed on the L5 mammillary process, 500 to 1200 mV amplitude action potential discharges were recorded. Several smaller discharges adjacent to the main peaks, which lasted for approximately 1 second, followed (Fig 8).

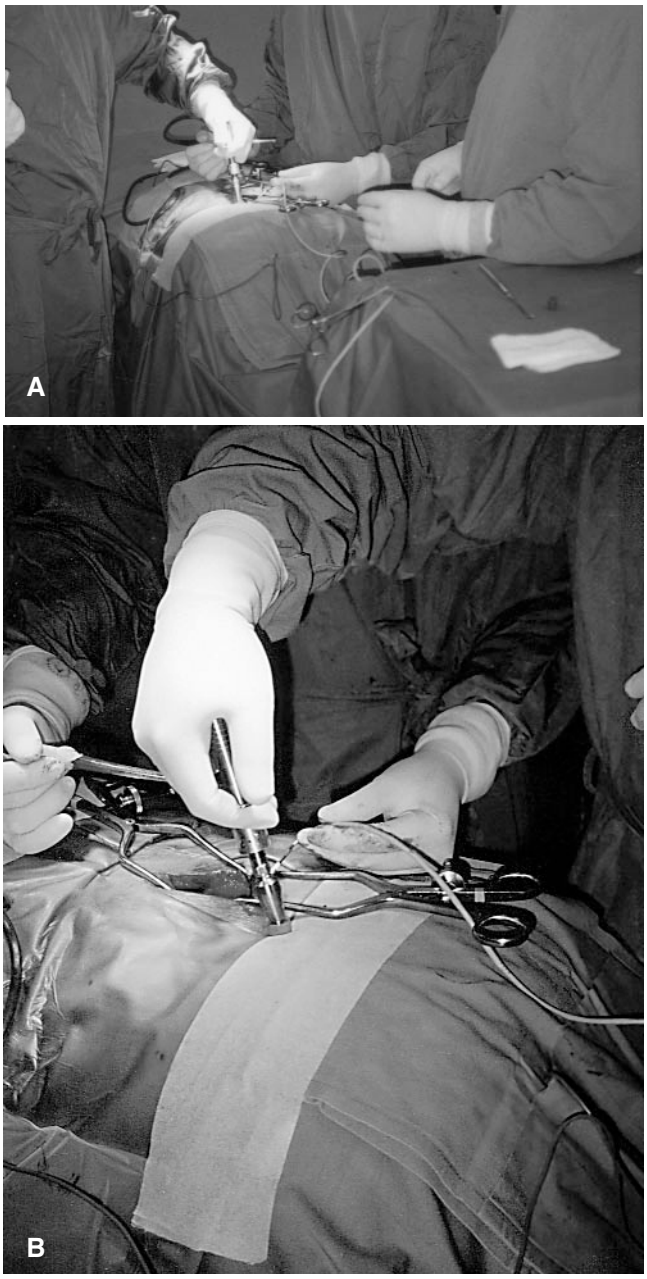

Fig 6. ***A****, Photograph depicting an external SMT being delivered with the AAI II on the sacral base.* ***B****, Higher magnification photograph showing the anterior-inferior force vector of the external sacral SMT. Also shown are the tissue retractors, suction (upper left), and electrode wiring in place.*

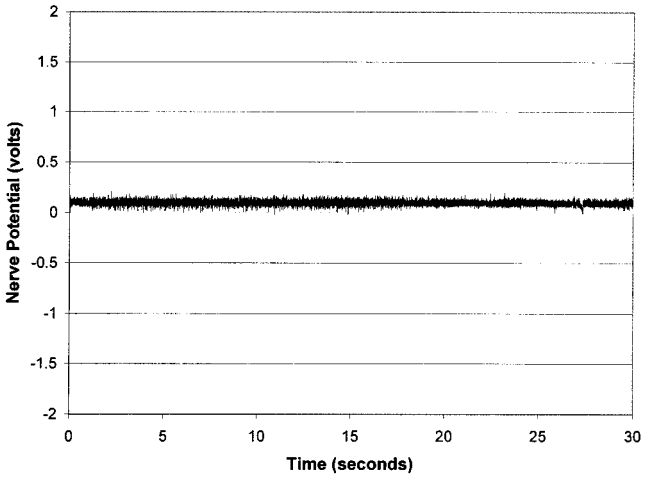

Fig 7. *Original recording of the right S1 nerve root obtained when the AAI II was placed on the right L5 mammillary process with a slight preload. No spinal manipulative thrusts were delivered. Raw data with the IIR filtered response superimposed are presented.*

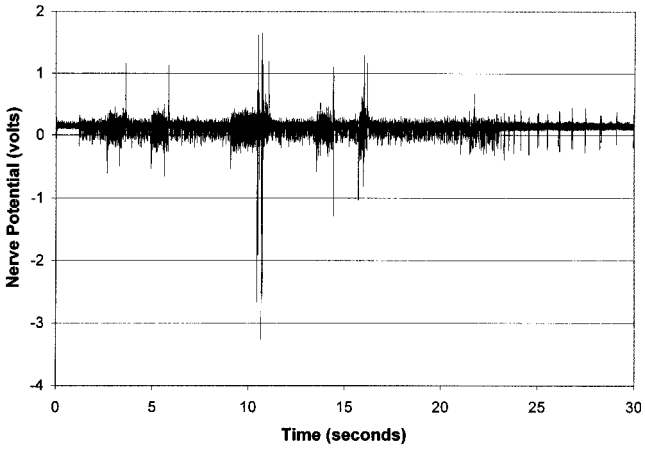

Fig 8. *Original recording of the right S1 nerve root during internal spinal manipulative thrusts.*

The 2 anterior-superior–vectored spinal manipulative thrusts performed on the superior L5 zygapophyseal joint also produced large magnitude (1200 to 2600-mV) responses (Fig 8). During the first 10 seconds, 4 anterior-vectored spinal manipulative thrusts were delivered directly on the L5 mammillary process. After these 4 thrusts, the AAI II was vectored anterior-superiorly, and the electrode inadvertently contacted the AAI II and moved approximately 0.5 cm proximal to the dorsal root ganglion producing 2 artifacts (at the 11-s time line; Fig 8). These artifacts produced considerably larger amplitude responses measuring 4400 to 4800 mV. Two spinal manipulative thrusts delivered in an anterior-superior vector on the L5 superior facet joint produced the largest amplitude action potentials. Nerve discharge was noted on preload of the zygapophyseal joint as well, but larger amplitude responses were observed during spinal manipulative thrusts than during the application of the joint preload. The AAI II was then moved to the sacral base, and beginning at approximately 22 seconds, a series of 12 internal spinal manipulative thrusts was applied to the right and left side of the sacral base in an anterior-inferior vector. The right side was contacted for the first 6 thrusts, followed by 6 thrusts on the left side.

Recordings of the right S1 nerve root during 12 internal spinal manipulative thrusts applied to the right and left sides of the sacral base in an anterior-inferior vector were found to produce smaller amplitude responses (200 to 900 mV) than those applied to the L5 level (Fig 8). Action potentials were of similar amplitude for contacts made on the left and right

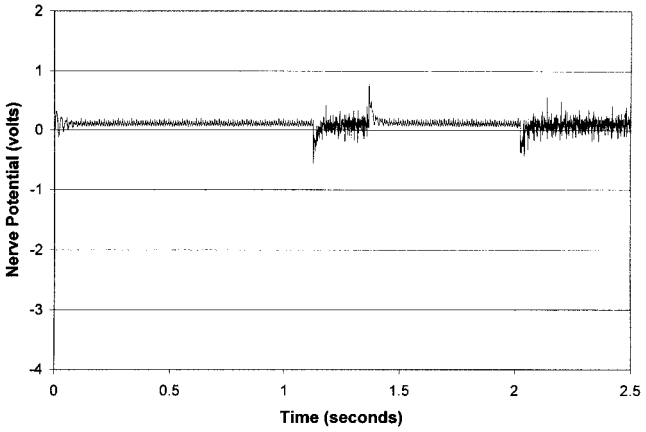

Fig 9. *Original recording of the right S1 nerve root during 2 anterior directed spinal manipulative thrusts delivered approximately 1 second apart to the skin overlying the right L5 mammillary process. Action potential discharges were of similar amplitude to those observed during mechanical stimulation internally by spinal manipulative thrusts applied directly on to the right L5 mammillary process (Fig 8).*

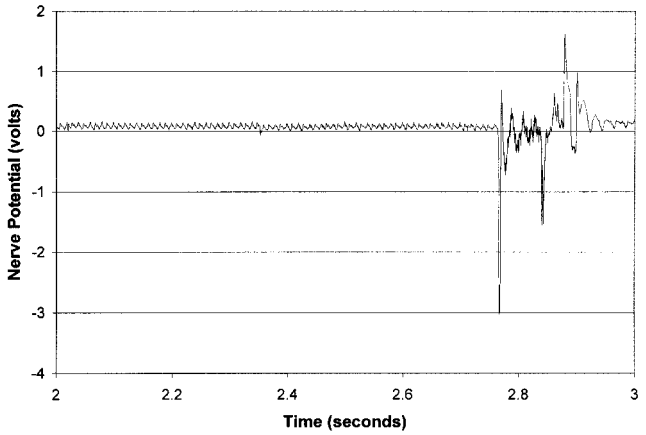

Fig 10. *Original recording of the right S1 nerve root during a single anterior-superior vectored SMT delivered to the skin overlying the right L5-S1 zygapophyseal joint. The peaks associated with these contacts were similar in magnitude to the internal spinal manipulative thrusts applied to the superior L5 zygapophyseal joint (Fig 8). The largest amplitude responses in the study were associated with the L5 anterior-superior vectored spinal manipulative thrusts.*

side. An increased discharge rate was also noted during the first 4 seconds of the recording, where the initial preload was applied to the segmental contact point on the right sacral base.

Active Recordings During External Spinal Manipulative Thrusts

For the anterior-directed external spinal manipulative thrusts delivered to the skin overlying the right L5 mammillary process, action potential amplitudes averaged approximately 1200 mV (Fig 9). These discharges were of similar amplitude to those observed during mechanical stimulation applied internally to the right L5 mammillary process.

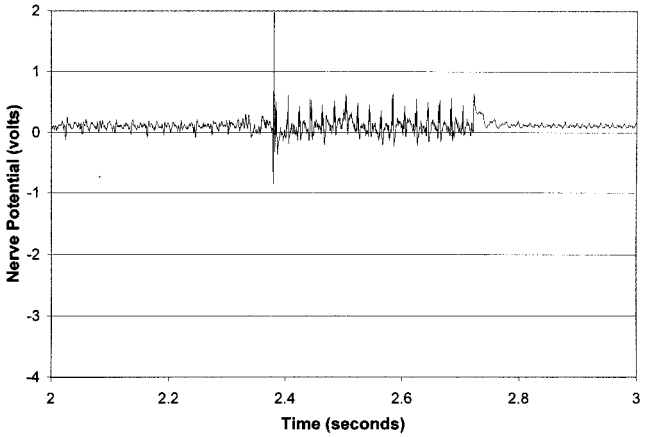

Fig 11. *Original recording of the right S1 nerve root during a single anterior-superior–vectored spinal manipulative thrust delivered to the skin overlying the right L5-S1 zygapophyseal joint. During this recording, the electrode lost contact with the nerve and abutted the adjacent musculature, producing an artifact with a characteristic signature illustrated by the presence of a large-amplitude (3000-mV) peak and numerous secondary peaks not observed in the other recordings.*

The largest responses for externally applied spinal manipulative thrusts were observed during the anterior-superior–vectored thrusts applied to the skin overlying the right L5-S1 zygapophyseal joint area. The amplitude of the action potential peaks associated with these contacts ranged from 800 to 3500 mV and was similar in amplitude to the internal spinal manipulative thrusts applied to the superior L5 zygapophyseal joint (Fig 10). On one occasion, the electrode lost contact with the nerve and abutted the adjacent musculature, producing an artifact with a characteristic signature illustrated by the presence of a large amplitude (3000 mV) peak and numerous secondary peaks (Fig 11).

For the 3 anterior-inferior–vectored external spinal manipulative thrusts delivered to each side of the sacral base, action potentials were also similar in amplitude to the internal thrusts performed on this level, averaging approximately 900 mV (Fig 12). One spinal manipulative thrust failed to produce any measurable neurophysiologic response and may have been caused by accumulation of tissue fluids in the region of the electrode placement, poor electrode contact, or a failure to mechanically stimulate the mixed nerve. Table 1 compares action potential responses between internal and external applied spinal manipulative thrusts.

DISCUSSION

Numerous publications have discussed different techniques of intraoperative spinal cord and nerve root recordings.[54-56] Intraoperative spinal cord monitoring with somatosensory-evoked potentials (SEPs) has been used to monitor nerve root decompression[57] and has become the standard of care for scoliosis surgery in the United States, reducing the incidence of postoperative myelopathy.[58,59] Dermatomal SEPs have been found to be more sensitive than mixed-

Table 1. *Average mixed-nerve root responses (mV) to spinal manipulative thrusts delivered internally and externally at different segmental levels and with differing force vectors*

	L5 Ant LOD	L5-Ant-sup LOD	S1-Ant-inf LOD
Internal spinal manipulative thrusts	500-1200	1200-2600	200-900
External spinal manipulative thrusts	1200	800-3500	900

LOD, Line of drive; *Ant,* anterior; *Sup,* superior; *Inf,* inferior.

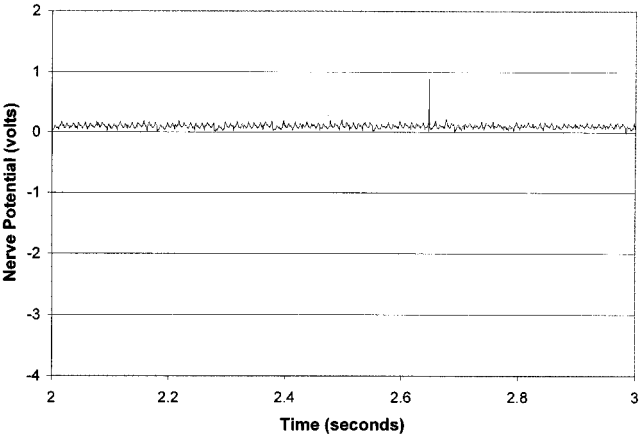

Fig 12. *Original recording of the right S1 nerve root during a single anterior-inferior–vectored spinal manipulative thrust delivered to the skin overlying the left sacral base. Discharges were similar in amplitude to the internal thrusts at this level (Fig 8).*

nerve SEPs for the detection of radiculopathy. However, dermatomal SEPs are of lower amplitude than mixed-nerve root potentials and require signal-averaging to yield reproducible data. Consequently, dermatomal SEPs are technically more difficult to perform in an operating room environment.[60-62] Monitoring of mixed-nerve root potentials from the lumbosacral nerve roots, however, provides a simple method for continuous assessment of real-time responses during mechanical stimulation and was deemed appropriate for our study.

Technical Issues

Several technical challenges had to be addressed in preparing for this study, most notably the short time frame available for measurements. Because prolonged operation times have been associated with an increase in surgical complications (including increased blood loss, postoperative spinal infection, and ischemic optic neuropathy),[63,64] collecting data in a timely manner from patients undergoing surgery becomes a significant challenge. As a result, patients are less willing to participate. For these reasons, the time allowed for experimental set-up and data collection was constrained to a minimum and therefore limited the number and type of experiments that could be performed.

The AAI II has been found to produce bone movement in in vivo animal and human studies.[15,16,18] Because other researchers have investigated neurophysiologic discharges after the applications of stresses and strains to the lumbar facet joints in animals,[20,22,24,25,28,31,65,66] we sought to determine the feasibility of obtaining intraoperative spinal nerve root neurophysiologic recordings in response to mechanical stimulation of somatic structures by SMT. To our knowledge, this study is the first to report in vivo lumbosacral nerve root action potential responses to SMT in human beings. Although the method was found to be feasible, for future work we plan to use an AAI II equipped with a load cell and accelerometer to quantify the threshold for mechanical stimulation and the temporal relation of the nerve root potential and mechanical stimulus frequency.[53] In addition, further study is required to more carefully identify artifacts associated with spinal manipulative thrusts.

In our experiment, we did not account for the temporal relation between the spinal manipulative thrust and the action potential responses and the sensitivity of the bipolar recording electrodes to movement. For this reason, a separate experiment was conducted with the same protocol discussed herein. Before applying spinal manipulative thrusts to the subject, the electrode was purposefully slid by the surgeon along the S1 nerve root approximately 1 cm during a 2.5-second data recording period. No appreciable action potential discharges were observed, confirming that the electrodes are not considerably movement sensitive (Fig 13). In this same experiment, SMT was next applied to the right L5 mamillary process with an anterior vector by an AAI II equipped with a load cell and accelerometer. Load and acceleration signals were analyzed during simultaneous S1 action potential recordings to provide the temporal relation between the spinal manipulative thrust and the nerve root discharge (Fig 14). In assessing the time line relations between the onset of mechanical stimulation during SMT and the resultant neurophysiologic response (2 to 4 ms), our findings were consistent with other neurophysiologic discharges recorded in response to mechanical and electrical stimulation.[30,31,66]

This Study

The aforementioned research has focused on responses to SMT delivered by contacting the skin overlying respective anatomic points, including the reflex-sensitive musculature. We sought to examine the feasibility of measuring mixed-nerve action potential responses to SMT delivered internally and externally (on the skin). Because of the limitations of human subjects, we were not able to measure discharges of individual rootlets or afferent units as is commonly reported in animal models, and we were not able to electrically stimulate the nerve and calculate the respective conduction velocities of the units. Our measurements were obtained from the region laterally adjacent to the dorsal root ganglion of S1, and therefore we could obtain only mixed-nerve root action potential responses to SMT. Appreciation of the possible peripheral sensitization effects of underlying inflammation leads us to choose the asymptomatic S1 nerve root for our source of data collection as opposed to recording from L5 or L4 levels in this particular patient.

In this study, mixed-nerve action potentials were observed in association with both internal and external spinal manipu-

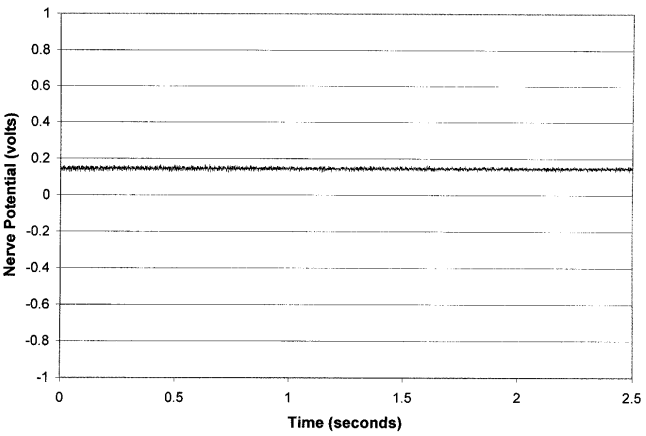

Fig 13. *During a 2.5-second experimental data recording period, the electrode was purposefully slid by the surgeon approximately 1 cm along the S1 nerve root to test the sensitivity to motion. No appreciable artifacts were observed.*

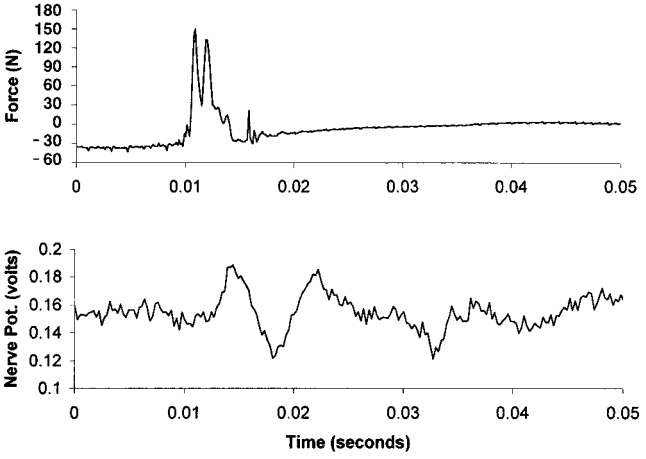

Fig 14. *S1 mixed-nerve root action potential in relation to the force-time history of the AAI II delivered to the right mammillary process of L5 with an anterior vector. Note that there is an approximate 2-ms delay after initiation of the AAI II thrust. In this experiment (as opposed to the others presented), a Biopac EMG100B bipotential amplifier module (100 to 5000 Hz bandwidth) was used to condition the recorded signals from a bipolar electrode (019-400900, Nicolet Biomedical Inc, Madison, Wis). The amplified condition signal depicted over a 50-ms period accounts for the action potential characteristics shown.*

lative thrusts delivered with the AAI II. Internal thrusts that contacted the L5 mammillary process and zygapophyseal joint during the active 30-second trial produced mixed-nerve root action potentials that were larger in magnitude when the force vector was anterior-superior compared with anterior only. Because the internally delivered spinal manipulative thrusts were not delivered to the overlying paraspinal musculature, the source of the mixed nerve-root discharge probably originated from discoligamentous mechanosensitive afferents in the posterior elements of the spine (intervertebral disk, zygapophyseal joint, and spinal ligaments) or from nerve root stimulation produced by bone movement. Preload of the zygapophyseal joint may also stimulate mechanosensitive afferents by stretching of the facet joint capsule. The actual sources of the action potentials, however, are not readily discernible. For unresponsive spinal manipulative thrusts, poor electrode contact or accumulation of fluid in the area of the electrodes may have caused the results. Another consideration may have been a simple failure to stimulate the nerve root from the thrusts.

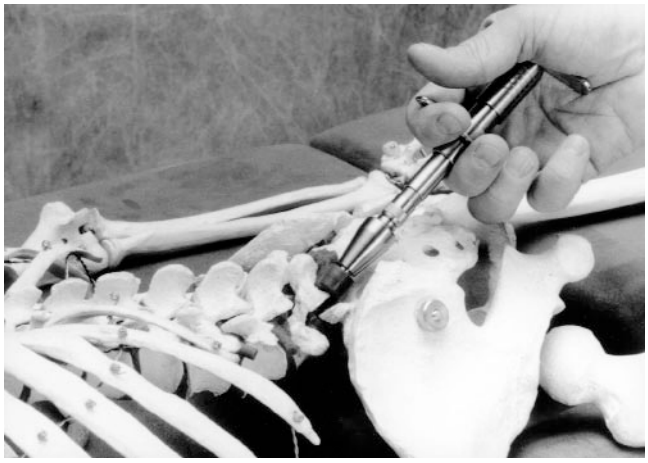

Fig 15. *Proper vector for chiropractic adjustment of the left L5-S1 zygapophyseal joint. The anterior-superior, applied-force vector provides the appropriate line of drive for maximal deformation of the joint. Reproduced with permission from Fuhr et al.*[67]

The apparent directional sensitivity of mixed-nerve action potential discharge demonstrated by the larger magnitude responses during the anterior-superior–vectored thrusts on the zygapophyseal joint may be caused by increased stretching of the joint capsule associated with this force vector. Because of the anatomic positioning of the zygapophyseal joints, it stands to reason that an anterior-superior–vectored force will cause the maximum deformation during a posteroanterior thrust. Consequently, this may evoke a greater mechanoreceptive response by stimulating underlying afferent units. A similar response from afferent discharges from the lumbar facet joints was also reported in animal studies when forces were applied in different directions and magnitudes.[20,24,25,31] Ideally, action potential measurements should be performed while simultaneously measuring translations and rotations of functional spinal units during the application of SMT force vectors. This is considered an essential element for future research.

Another example of the directional sensitivity of the mixed-nerve root response was demonstrated by thrusts applied to the sacral base, where the smallest amplitude discharge responses were observed. The reduced response may reflect that the sacral base is a stiff, anatomic connection of the sacrum with its articulating pelvis. Thrusts applied to the sacral base may not create stretching of the lumbar facet joint to the same extent as thrusts applied to L5. If this is the case, a decreased mechanosensitive afferent response would be expected. Of further interest are the similarities of mixed-nerve root responses in comparing thrusts delivered internally with those delivered externally by contacting the skin

overlying the respective anatomic points. Because the applied vector was found to be associated with mixed-nerve root discharge amplitude, it appears that the line of drive (force vector) of the AAI II may be important in providing stretch of the lumbar facet joint (Fig 15). Because the segmental contact point for the externally applied thrusts was on the skin overlying the underlying anatomical landmarks, it is likely that the mechanosensitive afferent response may originate in the skin, muscle, and discoligamentous tissues.

Of interest to the chiropractic profession is the apparent specificity of the chiropractic adjustment. As shown in previous animal models and as is apparent in our study, distractive and compressive loads have resulted in differing neurophysiologic responses. If therapy is to be effective, the directional sensitivity of mechanosensitive afferents provides a rationale for the need for appropriate education and training of the practitioner who applies SMT. This may have important implications for chiropractic education and the legislative efforts concerning the abilities of untrained individuals attempting to embark on spinal manipulation as an intervention within their scope of practice.

The beneficial effects of spinal manipulation have been thought to be associated with mechanosensitive afferent stimulation and presynaptic inhibition of nociceptive afferent transmission in the modulation of pain.[44,45] Our work has demonstrated that mixed-nerve root action potential responses are associated with SMT. However, we were not able to determine constituent components of fiber type. Because similar amplitude discharges were observed with the anterior-superior–vectored thrusts both internally and externally, we hypothesize that stimulation of mechanosensitive discoligamentous and muscular afferents may be responsible for the results. Further study is necessary to determine the underlying source of the mixed-nerve root signal. Such studies will most likely require an animal model because of the invasiveness of the dissection and stimulation required. We aim in future work to simultaneously monitor nerve roots and neuromuscular responses to compare temporally to the spinal manipulative thrust and bone movement. Future work should also include basic science investigations of the effect of SMT on inhibition of hypertonic muscles, together with biomechanic measures to assist in the clinical usefulness of this research.

CONCLUSION

As demonstrated by data obtained in this study, it is possible to record mixed-nerve action potentials in response to spinal manipulative thrusts in vivo in human subjects undergoing lumbar spinal surgery. The amplitude of mixed-nerve root action potentials was associated with the applied force vector of the SMT and segmental contact point. Further research is required to investigate the sources of nerve stimulation and the clinical relevance of these findings. Ultimately, such research may help to provide a greater understanding of the neurophysiologic mechanisms of spinal manipulation and to identify the mechanisms involved more precisely and will form the basis for further study in both human beings and animals.

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