Published in final edited form as:
J Manipulative Physiol Ther. 2013 ; 36(9): . doi:10.1016/j.jmpt.2013.08.007.

Effects of unilateral facet fixation and facetectomy on muscle spindle responsiveness during simulated spinal manipulation in an animal model

William R. Reed, DC, PhD [Associate Professor], **Cynthia R. Long, PhD [Professor]**, and **Joel G. Pickar, DC, PhD [Professor Emeritus]**
Palmer Center for Chiropractic Research

Abstract

Objectives—Manual therapy practitioners commonly assess lumbar intervertebral mobility before deciding treatment regimens. Changes in mechanoreceptor activity during the manipulative thrust are theorized to be an underlying mechanism of spinal manipulation (SM) efficacy. The objective of this study was to determine if facet fixation or facetectomy at a single lumbar level alters muscle spindle activity during 5 SM thrust durations in an animal model.

Methods—Spinal stiffness was determined using the slope of a force-displacement curve. Changes in the mean instantaneous frequency of spindle discharge were measured during simulated SM of the L_6 vertebra in the same 20 afferents for laminectomy-only, 19 laminectomy & facet screw conditions; only 5 also had data for the laminectomy & facetectomy condition. Neural responses were compared across conditions and five thrust durations (≤ 250ms) using linear mixed models.

Results—Significant decreases in afferent activity between the laminectomy-only and laminectomy & facet screw conditions were seen during 75ms (P<.001), 100ms (P=.04) and 150ms (P=.02) SM thrust durations. Significant increases in spindle activity between the laminectomy-only and laminectomy & facetectomy conditions were seen during the 75ms (P<.001) and 100ms (P<.001) thrust durations.

CORRESPONDING AUTHOR CONTACT INFORMATION William R. Reed DC, PhD, william.reed@palmer.edu, 741 Brady Street, Davenport, IA 52803, Phone number 563-884-5145, Fax number 563-884-5227.

Human Subjects and Animals
All experiments were reviewed and approved by the Palmer Institutional Animal Care and Use Committee.

CONFLICTS OF INTEREST
No conflicts of interest were reported for this study.

Contributorship
Concept development (provided idea for the research) WRR, JGP
Design (planned the methods to generate the results) WRR, JGP
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript) WRR, JGP
Data collection/processing (responsible for experiments, patient management, organization, or reporting data) WRR, JGP, CRL
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results) WRR, JGP, CRL
Literature search (performed the literature search) WRR
Writing (responsible for writing a substantive part of the manuscript) WRR
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking) WRR, JGP,CRL
Other (list other specific novel contributions)

Conclusion—Intervertebral mobility at a single segmental level alters paraspinal sensory response during clinically relevant high velocity low amplitude SM thrust durations (≤150ms). The relationship between intervertebral joint mobility and alterations of primary afferent activity during and following various manual therapy interventions may be used to help to identify patient subpopulations who respond to different types of manual therapy and better inform practitioners (eg, chiropractic, osteopathic) delivering the therapeutic intervention.

Keywords

Manipulation, Spinal; Muscle Spindle; Zygapophyseal Joint; Neurons, Afferent; Chiropractic

INTRODUCTION

Intervertebral hypomobility can be described as an increase in spinal stiffness or a reduction in motion between adjacent spinal segments. Conversely, intervertebral hypermobility represents decreased spinal stiffness and increased intervertebral motion. Clinical diagnoses associated with spinal joint hypomobility include degenerative joint disease including facet degeneration, osteophyte formation, or increased tears in the innervated outer rim of the intervertebral discs that are often associated with low back pain (LBP).[1–8] Increased or excessive joint motion has been clinically associated with rheumatoid arthritis, joint hypermobility syndrome, spondylolisthesis, facet/disc degeneration, and LBP.[9–15]

Spinal manipulation, which typically is applied to improve aberrant vertebral motion, has been shown to be clinically effective in the treatment of both neck pain and LBP.[8,16–18] Therapeutic benefits have been ascribed to mechanically breaking adhesions in hypomobile zygapophyseal joints[19–22] and/or to the subsequent neurophysiological consequences associated with improved vertebral joint motion.[23–25] Greater clinical efficacy may be found by identifying responsive subpopulations based upon their spinal stiffness or intervertebral joint mobility.[8,26–28] In a randomized clinical trial Fritz et al.[8] categorized 131 LBP patients with respect to the clinical determination of spinal joint hypo- and hypermobility and found that spinal manipulation produced higher therapeutic success rates in subjects with spinal joint hypomobility compared to those with spinal joint hypermobility. Subjects with spinal joint hypomobility had treatment success rates of 74 % after receiving spinal manipulation combined with stabilization exercises vs 25.6 % after receiving stabilization exercises alone. In contrast, subjects with spinal joint hypermobility had success rates of only 16.7 % with spinal manipulation combined with stabilization exercises but 77.8 % with stabilization exercises alone. The mechanisms responsible for this treatment effect are unknown but alterations in sensorimotor processing due intervertebral joint dysfunction may be a contributing factor.[24]

Patients with LBP have shown a variety of sensorimotor abnormalities including abnormal reflex responses indicated by reduced reflex gain and slowed reaction latencies, [29–32] impaired lumbosacral proprioceptive acuity,[33–37] dysfunction in trunk muscle response and control,[38–42] altered postural balance strategies,[30,43,44] and higher spinal loads during highly controlled exertions.[45] Many of these abnormalities are consistent with alterations in sensory feedback from the paraspinal tissues. Spindles in paraspinal muscles provide the central nervous system with sensory information regarding changes in muscle length and shortening velocity and thus are the proprioceptors most likely reporting changes in intervertebral position and aberrant vertebra movement. Pickar et al.[46,47] have shown that very small displacements (0.5-1.0 mm) of lumbar vertebra evoke muscle spindle discharge from paraspinal muscles and that sustained vertebral positions can affect the accuracy of proprioceptive signaling.

The apparent relationship between intervertebral joint mobility and the clinical success of spinal manipulation for LBP, combined with increasing evidence for proprioceptive-related changes in individuals with LBP led us to undertake a basic science investigation to determine the relationship between changes in lumbar spinal stiffness and mechanoreceptor activity from muscle spindles in the low back during a simulated High Velocity Low Amplitude spinal manipulation (HVLA-SM) in an animal preparation. The purpose of this study was to determine whether relative increases versus decreases in spinal stiffness can impact paraspinal sensory sensory responses over 5 thrust durations of HVLA-SM directed at the same level as the dysfunction. This study aims to be an important first step in concurrently examining the effects of intervertebral dysfunction and peripheral afferent signaling during a commonly used and effective therapeutic intervention for LBP.

METHODS

All experiments were reviewed and approved by our Institutional Animal Care and Use Committee. Electrophysiological activity in single primary afferent fibers from muscle spindles was obtained during HVLA-SM of the lumbar spine in 23 male cats weighing an average of 4.46 kg (SD 0.31). One afferent was investigated per cat because of the irreversible nature of the $L_{5/6}$ facetectomy surgical procedure.

General Procedures

The surgical procedures and device used to apply simulated spinal manipulations have previously been described in detail.[48,49] Briefly, anesthesia was induced using isoflurane and catheters placed in a carotid artery and an external jugular vein to monitor blood pressure and introduce fluids respectively. Deep anesthesia was then maintained throughout the experiment with Nembutal (35 mg/kg, iv). The trachea was intubated and the cat ventilated mechanically. Arterial pH, PCO_2, and PO_2 were monitored and maintained within the normal range (pH 7.32-7.43; PCO_2, 32-37 mmHg; PO_2, >85 mmHg). The right sciatic nerve was cut to reduce afferent input from the hindlimb. The lumbar spine was mechanically secured at the L_4 spinous process and the iliac crests using a Kopf spinal unit (David Kopf Instruments, Tujunga, CA). The L_5 laminae and caudal half of the L_4 laminae were removed to expose the L_6 dorsal rootlets. All intervertebral discs and facet joints remained intact. The dura mater was incised and the L_6 dorsal root was cut close to the spinal cord. Thin filaments from the cut proximal dorsal rootlets were teased using forceps until impulse activity from a single afferent was identified. The L_6 spinal nerve innervates the fascicles of the multifidus and longissimus muscles attaching to the L_6 vertebra.[50] Action potentials were recorded using a PC based data acquisition system (Spike 2, Cambridge Electronic Design, UK).

Calibrated nylon monofilaments (Stoelting, IL) were applied to the exposed back muscle (longissimus or multifidus) to verify the location of the most sensitive portion of the afferent's receptive field. Afferents were identified as muscle spindles based upon their increased discharge to succinylcholine (100 – 400 mg/kg; Butler Schein, OH), decreased discharge to electrically induced muscle contraction, and sustained response to a fast vibratory stimulus.[51–53] Animals were euthanized at the end of the experiment by an intravenous overdose of pentobarbital.

Determination of Spinal Stiffness

Changes in spinal stiffness relative to a laminectomy-only control condition were created by unilateral (left) $L_{5/6}$ facet-fixation (to increase intervertebral stiffness) or $L_{5/6}$ facetectomy (to decrease intervertebral stiffness). A previous study using a similar feline model showed that the average spinal stiffness did not differ significantly before and after the laminectomy

NIH-PA Author Manuscript

NIH-PA Author Manuscript

procedure itself.[54] Stiffness testing was done under the same conditions for which the neural recordings were obtained, namely in the necessary presence of a laminectomy. To fixate the left $L_{5/6}$ facet joint, a single 10mm titanium endosteally-anchored mini-screw (tomas®-pin; Dentaurum, Germany) was inserted through the articular pillars of the $L_{5/6}$ facet joint (Fig. 1). For the facetectomy, the left L_5 inferior facet and left L_6 superior facet were completely removed using bone rongeurs (Fig. 1). Muscle spindle responsiveness during the thrust of the HVLA-SM was tested in each of these three spinal joint conditions in the same animal. The testing order was always the same (laminectomy-only, laminectomy & facet screw, laminectomy & facetectomy) due to the irreversible nature of the facetectomy (Fig. 2).

Spinal joint stiffness was determined for each of the three spinal joint conditions using a 1mm ramp movement applied in the dorsal-ventral direction at the L_6 vertebra. Ramp movements were applied 5 minutes prior to delivery of the HVLA-SM thrusts. A feedback-controlled motor (Aurora Scientific, Lever System Model 310) induced vertebral movement at a rate of 0.5 mm/s through a pair of rigid forceps attached to the L_6 spinous process. This device and rate have been used in previous studies to assess stiffness in a feline preparation.[55,56] Forces and displacements applied at the L_6 spinous process were simultaneously measured from outputs of the control system. The slope of the most linear portion of the force-displacement curve (between 2.16 – 8.83 N) was calculated and represented pre-manipulation spinal joint stiffness for each condition. Pre-conditioning was not performed in order to minimize the total number of facet screw/bone engagements. Preliminary testing indicated that spinal joint stiffness created by insertion of the facet screw remained unchanged through a minimum of 16 manipulative procedures which was over 3x the number performed after screw insertion in the present study. To confirm that during the manipulation thrust itself, the screw maintained the increase in stiffness and that the facetectomy decreased it relative to laminectomy-only, spinal stiffness was also determined during each manipulative thrust. Stiffness during the thrust was obtained from the slope of the force-displacement curves from thrust onset to peak thrust amplitude for each condition.

Twenty-three animals were used in this study. In the laminectomy & facet screw condition, the screw failed to decrease the 1mm ramp stiffness by at least 2 % in 4 animals. Therefore, only 19 laminectomy & facet screw conditions were compared to the laminectomy-only condition (Fig. 2). In the laminectomy & facetectomy condition, facetectomy failed to increase the 1mm ramp stiffness by at least 2 % in 8 animals. In addition, due to surgically-associated bleeding during the facetectomy procedure (performed following removal of the facet screw) the neural signal was lost in another 10 laminectomy & facetectomy conditions. Therefore, only 5 laminectomy & facetectomy conditions were compared to the laminectomy-only condition (Fig. 2).

Mechanical loading profiles measured during a clinically delivered HVLA-SM indicate that the thrust phase of a spinal manipulation can be likened to the up-ramp of a triangle wave.[57–59] Peak manipulative forces during clinical treatment of the lumbosacral region can range from 200 to 1600 N with a time to peak force being <150 ms.[57,59–62]

Simulated HVLA-SM thrusts were applied at the L_6 spinous process using the same feedback motor control system and toothed forceps used for stiffness determination. Peak manipulative forces of 55 % of an average cat body weight (3.95 kg as determined in previous studies[49,53]) were applied in a dorsal-ventral direction (i.e. from the cat's posterior toward its anterior) under force control. Forces were applied over 5 thrust durations (0-time control, 75, 100, 150, 250 ms). The time-control (0 ms duration) represents a non-thrust testing protocol from which potential changes in discharge frequency related to surgical procedures could be determined. The range of thrust durations encompassed those used clinically with non-instrument assisted HVLA-SMs.[57,59] Spinal manipulations were separated by 5 minutes[53] and order was randomized within each of the 3 types of joint conditions (Fig. 2).

Data analysis

Muscle spindle activity was converted to instantaneous frequency (IF) by taking the reciprocal of the time interval between successive action potentials. Neural activity arising from HVLA-SM activation of muscle spindles was determined during the 2 seconds that immediately preceded each HVLA-SM thrust (baseline) and during the HVLA-SM's thrust phase. Mean IF (MIF) was calculated for baseline and the thrust phase. As in previous studies, the change in MIF resulting from the HVLA-SM (ΔMIF) constituted the response measure.[49,53] All neural activity is reported in impulses per second (imp/s).

The study was a split-plot design[63] where the whole-plot factor, thrust duration, was a randomized complete block design and the sub-plot factor, spinal joint condition, was a repeated measures design. The data were analyzed with Proc Mixed in SAS System for Windows (Release 9.2) (SAS Institute Inc., Cary, NC). Linear mixed models of both lumbar stiffness and neural response were fit with terms for thrust duration, spinal joint condition and their interaction, modeling within block correlation over the three conditions as unstructured. Twenty afferents were included in the analysis; 4 had data for all 3 conditions (laminectomy-only, laminectomy & facet screw, laminectomy & facetectomy), 15 had data for the laminectomy-only and laminectomy & facet screw conditions, and 1 had data for the laminectomy-only and laminectomy & facetectomy conditions. Residual plots were used to confirm model assumptions. Comparisons between durations and among conditions were tested using linear contrasts. Statistical significance was set at 0.05. Adjusted means and 95 % confidence intervals based on the above model are reported unless otherwise noted.

RESULTS

Single unit recordings were obtained from afferents that were responsive to dorsal-ventral movement of the L_6 vertebra. The receptive field for each of the 20 afferents was located in either the L_6 longissimus (n=17) or multifidus (n=3) paraspinal muscle. Succinylcholine injection (100 – 400 mg/kg, intra-arterially) induced high frequency and long lasting discharge in all afferents and each afferent exhibited a sustained response to a vibratory stimulus. In addition, all afferents were unloaded by bipolar muscle stimulation (amplitude 0.1 – 0.3 mA: 50 μs).

Effect of facet-fixation and facetectomy on baseline spinal stiffness

In the laminectomy-only condition, the pre-manipulation 1mm ramp mean spinal stiffness measured at L_6 was 11.51 N/mm (range 6.39 to 18.23 N/mm). Compared to the laminectomy-only preparation, the mean increase in pre-manipulation spinal stiffness resulting from the laminectomy & facet screw was 4.02 N/mm (range: 1.08 to 7.75 N/mm). Mean pre-manipulation spinal stiffness resulting from the laminectomy & facetectomy decreased −1.18 N/mm (range of −0.69 to −2.26 N/mm).

The thrust duration by joint condition interaction ($F_{6,89}$ =.56, p=.76) and differences among thrust duration ($F_{3,56}$, =.06, p=.98) for lumbar stiffness were not significant. Compared to the laminectomy-only condition, the laminectomy & facet screw significantly increased mean spinal thrust stiffness by 4.8 N/mm (p<.001) while the laminectomy & facetectomy significantly decreased mean spinal thrust stiffness by 0.4 N/mm (p=.01). Compared to the laminectomy & facet screw condition, the mean change (−5.2 N/mm) in spinal stiffness due to the laminectomy & facetectomy was also significant (p<.001).

Effect of spinal joint condition on neural discharge

There was a significant thrust duration by joint condition interaction ($F_{8,110} = 3.64$, P<.001). Therefore, thrust duration and joint condition could not be interpreted separately. Adjusted means and 95 % confidence intervals of afferent activity between thrust durations for each facet joint condition are shown in Figure 3. Regardless of condition, significant differences in ΔMIF were found between the shortest thrust duration (75 ms) and the two longest thrust durations of 150 ms and 250 ms.

Figure 4A shows the differences in afferent activity during each of the five L_6 thrust durations (0-time control, 75, 100, 150, 250 ms) between the laminectomy-only condition and the laminectomy & facet screw condition. The laminectomy & facet screw condition produced a significantly larger decrease in adjusted mean ΔMIF during the thrust durations of 75 ms (P<.001), 100 ms (P=.04), and 150 ms (P=.02) when compared to the laminectomy-only condition. The largest mean difference in afferent activity occurred at the shortest thrust duration of 75 ms (Fig. 4A). No differences in ΔMIF were seen either in the time-control or at the longest thrust duration of 250 ms. The lack of changes within the time-control indicates the inherent stability of baseline afferent discharge over the duration of the experiments despite multiple manipulations and procedures having been performed.

In contrast to the decrease in spindle discharge during the HVLA-SM thrust caused by increasing intervertebral stiffness via the laminectomy & facet screw, spindle discharge increased during the HVLA-SM thrust when stiffness was decreased by the laminectomy & facetectomy (Fig. 4B). Comparing differences in afferent activity between the laminectomy-only conditions and laminectomy & facetectomy condition, significantly larger increases in mean spindle discharge occurred during the two shortest thrust durations 75 and 100 ms (P<.001; Fig. 4B). Unlike in the laminectomy & facet screw condition, mean ΔMIF in the laminectomy & facetectomy condition were not significant for either the 150 and 250 ms thrust durations in the laminectomy & facetectomy condition (Fig. 4). There was no change in the time-control afferent discharge between the laminectomy-only and laminectomy & facetectomy conditions.

DISCUSSION

This study indicates that biomechanical dysfunction at a single facet joint impacts how mechanoreceptive afferents respond to delivery of an HVLA spinal manipulative thrust. Whereas increased spinal stiffness decreased muscle spindle responses, decreased spinal stiffness increased it during clinically relevant HVLA-SM thrust durations (≤150 ms). Because spinal stiffness had little effect on spindle responses during HVLA-SM when its thrust duration was longer than that typically used clinically (i.e. at the 250 ms thrust duration), sensory input from paraspinal muscle spindles during slower manual therapeutic interventions (≥250 ms) may not be impacted by facet joint dysfunction (at a single joint level at least).

These findings may have implications for clinical decision making if maximizing sensory input from segmental paraspinal tissues is important for optimizing manual therapy's therapeutic benefit. Knowledge of spinal stiffness[27] and manipulative dosage [49,64] (e.g. the magnitude of thrust duration and peak thrust amplitude) may be critical factors for determining the most effective manual therapy treatment regimens. Based on the results from a single facet fixation, one could speculate that in clinical conditions where intervertebral mobility is decreased such as advanced degenerative disc or joint disease, clinicians may need to alter their treatment approach in order to create greater levels of "afferent barrage" from paraspinal mechanoreceptors if this is indeed an essential component of the mechanisms underlying the efficacy of spinal manipulation as has been theorized.[24,65]

The general relationship between HVLA-SM thrust duration in the laminectomy-only condition and changes in muscle spindle activity in the present study was similar to that previously reported in the same animal model.[48,49] Overall, as thrust durations became shorter, muscle spindle discharge frequency increased (Fig. 3). This relationship was presumably due primarily to a muscle spindle's inherent sensitivity to the rate change in muscle length. Intervertebral joint dysfunction (at a single facet joint) did not alter this inherent sensitivity.

Implications for clinical practice

In clinical practice, practitioners of manual therapy typically consider segmental levels with increased stiffness as being in need of manipulation.[8,26,75] Reducing facet joint hypomobility itself has been hypothesized as an underlying mechanism of the beneficial effect of HVLA-SM.[20,21,23] This study indicates that relative increases versus decreases in spinal stiffness caused by intervertebral dysfunction at a single facet joint can impact paraspinal sensory responses during clinically relevant HVLA-SM thrust durations (≤150ms) directed at the same segmental level as the dysfunction. More specifically, the laminectomy & facet screw condition significantly decreased paraspinal muscle spindle discharge during thrust durations of 75 ms, 100 ms and 150 ms; whereas the laminectomy & facetectomy condition significantly increased paraspinal muscle spindle discharge at 75 ms and 100 ms. The relationship between intervertebral joint mobility and alterations of primary afferent activity during and following these shorter duration manual therapy interventions may provide (at least in part) an explanation for clinical prediction rules that successfully use intervertebral joint dysfunction to identify patient subpopulations who respond to different types of manual therapy.

Limitations

The present study was limited to the effects of intervertebral dysfunction at a single spinal joint. In a clinical setting, acute and chronic LBP patients are often assessed as having dysfunctional joints at multiple segmental levels with additional confounding factors such as advanced facet and/or disc degeneration, muscle spasm, pain, and/or joint inflammation. The animal model used in the current study is an attempt to investigate the effects of the simplest degree of intervertebral joint dysfunction on paraspinal sensory input. Although the method used to create segmental fixation was invasive, it produced a lesser degree of total spinal joint dysfunction than the more aggressive intervertebral body fixation techniques incorporating instrumentation such as steel rods and/or intervertebral cages. By not anteriorly fixating the lumbar vertebral bodies, the current facet joint dysfunction model may provide greater similarity to the total degree of segmental dysfunction (at a given vertebral level) commonly observed in clinical manual therapy settings. That said, future studies should investigate greater degrees of joint dysfunction (multiple facet joints at the same or adjacent segmental levels) and/or the effect of degenerative/inflammatory processes on paraspinal mechanoreceptor activity during and following manual therapy interventions.

Although most spinal manipulative maneuvers include a posterior-anterior component, rotary and/or other non-posterior-anterior thrust vectors are often used in clinical settings and their use should be considered in future studies. A rotary component was not part of the current study due to the increased risk it posed to tearing the afferent fiber off the recording electrode.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Although the HVLA-SM procedure causes relatively small movements between the manipulated and surrounding vertebrae (between 0.4 – 2.6 mm translation and 0.4-3.5° rotation);[66–68] ramp displacements that exceed 1mm for determining pre-manipulation spinal joint stiffness may provide a better estimate of initial spinal stiffness particularly due to the inherent flexibility of the cat spine.[69,70] However, the mean pre-manipulation spinal stiffness of 11.51 N/mm in the laminectomy-only condition was similar to that previously reported in the intact cat lumbar spine (6.07 to 12.14 N/mm[55]), the rat lumbar spine (14.52 N/mm[71]) and the lumbar spine of healthy human volunteers (~11 to 17 N/mm[72] and 14.05 to 16.41 N/mm[73]).

Failure to create a minimal change (2 %) in stiffness several preparations was likely the result of a combination of factors including but not limited to inadequate placement of the facet screw, partial splintering of the facet joint, incomplete facetectomy, the greater inherent flexibility of the feline spinal column, and/or biomechanical testing in the dorsal-ventral direction only as opposed to including lateral and/or rotary-type movements for which the facet joints play a greater role. Attempts should be made in future studies to eliminate as many of these factors as possible. Although the resulting number of preparations was small in the laminectomy & facetectomy condition, the statistical analysis indicated significant changes at the two shorter thrust durations; these findings should be confirmed in a powered study with minimal loss of preparations within the laminectomy & facetectomy condition.

The effects spinal joint dysfunction on muscle spindle discharge during HVLA-SM thrust durations of less than 10 ms such as those associated with instrumentdelivered HVLA-SM[74] was not determined in the current study. However in a laminectomy-only preparation, we recently reported that spindle discharge became asymptotic with increasing thrust rate and suggested the presence of threshold range of thrust rates (200-500 N/s) after which faster rates would provide little additional effect on the neural response compared to the shortest thrust duration of 75 ms.[49]

CONCLUSION

The findings of this study showed that relative increases versus decreases in spinal stiffness caused by intervertebral dysfunction at a single facet joint can impact paraspinal sensory responses during clinically relevant HVLA-SM thrust durations (≤150ms) directed at the same segmental level as the dysfunction.

The relationship between intervertebral joint mobility and alterations of primary afferent activity during and following various manual therapy interventions may be used to help to identify patient subpopulations who respond to different types of manual therapy and better inform practitioners delivering the therapeutic intervention.

Acknowledgments

Thanks to Randall Sozio for technical support and Dr. Robert Vining for radiology assistance.

FUNDING SOURCES

This study was funded by K01AT005935 to WRR and was conducted in a facility constructed with support from Research Facilities Improvement Grant Number C06 RR15433 from the NCRR, NIH.

References

1. Lee CK. Accelerated degeneration of the segment adjacent to a lumbar fusion. Spine. 1988; 13:375–377. [PubMed: 3388124]

NIH-PA Author Manuscript

NIH-PA Author Manuscript

2. Binkley J, Finch E, Hall J, Black T, Gowland C. Diagnostic classification of patients with low back pain: report of a survey of physical therapy experts. Phys Ther. 1993; 73:138–150. [PubMed: 8438002]

3. Schlegal JD, Smith JA, Schleusener RL. Lumbar motion segment pathology adjacent to thoracolumbar, lumbar, and lumbosacral fusions. Spine. 1996; 21:970–981. [PubMed: 8726202]

4. Thompson RE, Pearcy MJ, Downing KJ, Manthey BA, Parkinson IH, Fazzalari NL. Disc lesions and the mechanics of the intervertebral joint complex. Spine. 2000; 25:3026–3035. [PubMed: 11145814]

5. Abbott JH, Mercer SR. Lumbar segmental hypomobility: Criterion-related validity of clinical examination items (a pilot study). New Zeal J Physio. 2003; 31:3–9.

6. Cramer GD, Fournier JT, Henderson CN, Wolcott CC. Degenerative changes following spinal fixation in a small animal model. J Manipulative Physiol Ther. 2004; 27:141–154. [PubMed: 15129196]

7. Stokes IA, Iatridis JC. Mechanical conditions that accelerate intervertebral disc degeneration: overload versus immobilization. Spine. 2004; 29:2724–2732. [PubMed: 15564921]

8. Fritz JM, Whitman JM, Childs JD. Lumbar spine segmental mobility assessment: an examination of validity for determining intervention strategies in patients with low back pain. Arch Phys Med Rehabil. 2005; 86:1745–1752. [PubMed: 16181937]

9. Balague, F. Natural history of lumbar segmental instability. In: Szpalski, M.; Gunzburg, R.; Pope, MH., editors. Lumbar Segmental Instability. Philidelphia: Lippincott Williams & Wilkins; 1999. p. 63-74.

10. Fujiwara A, Tamai K, An HS, et al. The relationship between disc degeneration, facet joint osteoarthritis, and stability of the degenerative lumbar spine. J Spinal Disord. 2000; 13:444–450. [PubMed: 11052356]

11. Ferrell WR, Tennant N, Sturrock RD, et al. Amelioration of symptoms by enhancement of proprioception in patients with joint hypermobility syndrome. Arthritis Rheum. 2004; 50:3323–3328. [PubMed: 15476239]

12. Adib N, Davies K, Grahame R, Woo P, Murray KJ. Joint hypermobility syndrome in childhood. A not so benign multisystem disorder? Rheumatology. 2005; 44:744–750. [PubMed: 15728418]

13. Lotz JC, Ulrich JA. Innervation, inflammation, and hypermobility may characterize pathologic disc degeneration: review of animal model data. J Bone Joint Surg Am. 2006; 88-A:76–82. [PubMed: 16595449]

14. Kulig K, Powers CM, Landel RF, et al. Segmental lumbar mobility in individuals with low back pain: in vivo assessment during manual and self-imposed motion using dynamic MRI. BMC Musculoskelet Disord. 2007; 8:8. [PubMed: 17261197]

15. Fatoye F, Palmer S, Macmillan F, Rowe P, van der Linden M. Proprioception and muscle torque deficits in children with hypermobility syndrome. Rheumatology. 2009; 48:152–157. [PubMed: 19088133]

16. Hurwitz EL, Aker PD, Adams AH, Meeker WC, Shekelle PG. Manipulation and mobilization of the cervical spine. A systematic review of the literature. Spine. 1996; 21:1746–1759. [PubMed: 8855459]

17. Bronfort G, Haas M, Evans RL, Bouter LM. Efficacy of spinal manipulation and mobilization for low back pain and neck pain: a systematic review and best evidence synthesis. Spine J. 2004; 4:335–356. [PubMed: 15125860]

18. Goertz CM, Pohlman KA, Vining RD, Brantingham JW, Long CR. Patientcentered outcomes of high velocity, low-amplitude and spinal manipulation for low back pain: A systematic review. J Electromyogr Kinesiol. 2012; 22:670–691. [PubMed: 22534288]

19. Cramer GD, Tuck NR Jr, Knudsen JT, et al. Effects of side-posture positioning and side-posture adjusting on the lumbar zygapophysial joints as evaluated by magnetic resonance imaging: a before and after study with randomization. J Manipulative Physiol Ther. 2000 Jul.23:380–394. [PubMed: 10951308]

20. Cramer GD, Cambron J, Cantu JA, et al. Magnetic resonance imaging zygapophyseal joint space changes (gapping) in low back pain patients following spinal manipulation and side-posture

positioning: a randomized controlled mechanisms trial with blinding. J Manipulative Physiol Ther. 2013 http://dx.doi.org/10.1016/j.jmpt.2013.04.003.

21. Evans DW. Mechanisms and effects of spinal high-velocity, low amplitude thrust manipulation: previous theories. J Manipulative Physiol Ther. 2002; 25:251–262. [PubMed: 12021744]
22. Cramer GD, Henderson CN, Little JS, Daley C, Grieve TJ. Zygapophyseal joint adhesions after induced hypomobility. J Manipulative Physiol Ther. 2010; 33:508–518. [PubMed: 20937429]
23. Henderson CN. The basis for spinal manipulation: chiropractic perspective of indications and theory. J Electromyogr Kinesiol. 2012; 22:632–642. [PubMed: 22513367]
24. Pickar JG. Neurophysiological effects of spinal manipulation. Spine J. 2002; 2:357–371. [PubMed: 14589467]
25. Bialosky JE, Bishop MD, Price DD, Robinson ME, George SZ. The mechanisms of manual therapy in the treatment of musculoskeletal pain: a comprehensive model. Man Ther. 2009; 14:531–538. [PubMed: 19027342]
26. Abbott JH, Flynn TW, Fritz JM, Hing WA, Reid D, Whitman JM. Manual physical assessment of spinal segmental motion: intent and validity. Man Ther. 2009; 14:36–44. [PubMed: 17997344]
27. Fritz JM, Koppenhaver SL, Kawchuk GN, Teyhen DS, Hebert JJ, Childs JD. Preliminary investigation of the mechanisms underlying the effects of manipulation. Spine. 2011; 36:1772–1781. [PubMed: 21358568]
28. Henry SM, Fritz JM, Trombley AR, Bunn JY. Reliability of a treatment-based classification system for subgrouping people with low back pain. J Orthop Sports Phys Ther. 2012; 42:797–805. [PubMed: 22677525]
29. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain: a motor control evaluation of transversus abdominis. Spine. 1996; 21:2640–2650. [PubMed: 8961451]
30. Luoto S, Aalto H, Taimela S, Hurri H, Pyykko I, laranta H. One-footed and externally distrubed two-footed postural control in patients with chronic low back pain and healthy control subjects, A controlled study with follow-up. Spine. 1998; 23:2081–2089. [PubMed: 9794052]
31. Hodges P. Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. Arch Phys Med Rehabil. 1999; 80:1005–1012. [PubMed: 10489000]
32. Hodges PW, Tucker K. Moving differently in pain: a new theory to explain the adaptation to pain. Pain. 2011; 152:S90–S98. [PubMed: 21087823]
33. Gill KP, Callaghan MJ. The measurement of lumbar proprioception in individuals with and without low back pain. Spine. 1998; 23:371–377. [PubMed: 9507628]
34. Taimela S, Kankaanpaa M, Luoto S. The effect of lumbar fatigue on the ability to sense a change in lumbar position: a controlled study. Spine. 1999; 24:1322–1327. [PubMed: 10404574]
35. Brumagne S, Cordo P, Lysens R, Verschueren S, Swinnen S. The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. Spine. 2000; 25:989–994. [PubMed: 10767813]
36. Newcomer K, Laskowski ER, Yu B, Larson DR, An K. Repositioning error in low back pain: comparing trunk repositioning error in subjects with chronic low back pain and control subjects. Spine. 2000; 25:245–250. [PubMed: 10685490]
37. Brumagne S, Cordo P, Verschueren S. Proprioceptive weighting changes in persons with low back pain and elderly persons during upright standing. Neurosci Lett. 2004; 366:63–66. [PubMed: 15265591]
38. Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. Spine. 1996; 21:2763–2769. [PubMed: 8979323]
39. Radebold A, Cholewicki J, Panjabi MM, Patel TC. Muscle response pattern to sudden trunk loading in healthy individuals and in patients with chronic low back pain. Spine. 2000; 25:947–954. [PubMed: 10767807]
40. Chaing J, Potvin JR. The in vivo dynamic response of the human spine to rapid lateral bend perturbation. Spine. 2001; 26:1457–1464. [PubMed: 11458151]

41. Radebold A, Cholewicki J, Polzhofer GK, Greene HS. Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. Spine. 2001; 26:724–730. [PubMed: 11295888]

42. Reeves NP, Cholewicki J, Milner TE. Muscle reflex classification of low-back pain. J Electromyogr Kinesiol. 2005; 15:53–60. [PubMed: 15642653]

43. Henry SM, Hitt JR, Jones SL, Bunn JY. Decreased limits of stability in response to postural perturbations in subjects with low back pain. Clin Biomech. 2006; 21:881–892.

44. Brumagne S, Janssens L, Knapen S, Claeys K, Suuden-Johanson E. Persons with recurrent low back pain exhibit a rigid postural control strategy. Eur Spine J. 2008; 17:1177–1184. [PubMed: 18594876]

45. Marras WS, Davis KG, Ferguson SA, Lucas BR, Gupta P. Spine loading characteristics of patients with low back pain compared with asymptomatic individuals. Spine. 2001; 26:2566–2574. [PubMed: 11725237]

46. Pickar JG, Kang YM. Paraspinal muscle spindle responses to the duration of a spinal manipulation under force control. J Manipulative Physiol Ther. 2006; 29:22–31. [PubMed: 16396726]

47. Ge W, Pickar JG. The decreased responsiveness of lumbar muscle spindles to a prior history of spinal muscle lengthening is graded with the magnitude of change in vertebral position. J Electromyogr Kinesiol. 2012; 22:814–820. [PubMed: 22721784]

48. Pickar JG, Wheeler JD. Response of muscle proprioceptors to spinal manipulative-like loads in the anesthetized cat. J Manipulative Physiol Ther. 2001; 24:2–11. [PubMed: 11174689]

49. Reed WR, Cao DY, Long CR, Kawchuk GN, Pickar JG. Relationship between biomechanical characteristics of spinal manipulation and neural responses in an animal model: effect of linear control of thrust displacement versus force, thrust amplitude, thrust duration and thrust rate. Evid Based Complement Alternat Med. 2013 http://dx.doi.org/10.1155/2013/492039.

50. Bogduk N. The lumbosacral dorsal rami in the cat. J Anat. 1976; 122:653–662. [PubMed: 1010794]

51. Brown MC, Engberg I, Matthews PB. The relative sensitivity to vibration of muscle receptors of the cat. J Physiol. 1967; 192:773–800. [PubMed: 4293790]

52. Pickar JG. An in vivo preparation for investigating neural responses to controlled loading of a lumbar vertebra in the anesthetized cat. J Neurosci Methods. 1999; 89:87–96. [PubMed: 10491938]

53. Cao DY, Reed WR, Long CR, Kawchuk GN, Pickar JG. Effects of thrust amplitude and duration of high-velocity, low-amplitude spinal manipulation on lumbar muscle spindle responses to vertebral position and movement. J Manipulative Physiol Ther. 2013; 36:68–77. [PubMed: 23499141]

54. Pickar JG, Sung PS, Kang YM, Ge W. Response of lumbar paraspinal muscles spindles is greater to spinal manipulative loading compared with slower loading under length control. Spine J. 2007; 7:583–595. [PubMed: 17905321]

55. Vaillant M, Edgecombe T, Long CR, Pickar JG, Kawchuk GN. The effect of duration and amplitude of spinal manipulative therapy (SMT) on spinal stiffness. Man Ther. 2012; 17:577–583. [PubMed: 22809745]

56. Vaillant M, Pickar JG, Kawchuk GN. Performance and reliability of a variable rate, force/displacment application system. J Manipulative Physiol Ther. 2010; 33:585–593. [PubMed: 21036280]

57. Hessell BW, Herzog W, Conway PJW, McEwen MC. Experimental measurement of the force exerted during spinal manipulation using the Thompson technique. J Manipulative Physiol Ther. 1990; 13:448–453. [PubMed: 2146356]

58. Herzog W, Conway PJ, Kawchuk GN, Zhang Y, Hasler EM. Forces exerted during spinal manipulative therapy. Spine. 1993; 18:1206–1212. [PubMed: 8362328]

59. Triano JJ. Biomechanics of spinal manipulative therapy. Spine J. 2001; 1:121–130. [PubMed: 14588392]

60. Conway PJW, Herzog W, Zhang Y, Hasler EM, Ladly K. Forces required to cause cavitation during spinal manipulation of the thoracic spine. Clin Biomech. 1993; 8:210–214.

61. Triano J, Schultz AB. Loads transmitted during lumbosacral spinal manipulative therapy. Spine. 1997; 22:1955–1964. [PubMed: 9306523]
62. Herzog W. The biomechanics of spinal manipulation. J Bodyw and Mov Ther. 2010; 14:280–286. [PubMed: 20538226]
63. Jones B, Nachtsheim CJ. Split-plot designs: What, Why, and How? J Quality Technology. 2009; 41:340–361.
64. Gudavalli MR, DeVocht JW, Tayh A, Xia T. Effect of sampling rates on the quantification of forces, durations, and rates of loading of simulated side posture high-velocity, low-amplitude lumbar spine manipulation. J Manipulative Physiol Ther. 2013; 36:261–266. [PubMed: 23790603]
65. Korr IM. Proprioceptors and somatic dysfunction. J Am Osteopath Assoc. 1975; 74:638–650. [PubMed: 124754]
66. Nathan M, Keller TS. Measurement and analysis of the in vivo posteroanterior impulse response of the human thoracolumbar spine: a feasibility study. J Manipulative Physiol Ther. 1994; 17:431–441. [PubMed: 7989876]
67. Gal J, Herzog W, Kawchuk G, Conway PJ, Zhang YT. Movements of vertebrae during manipulative thrusts to unembalmed human cadavers. J Manipulative Physiol Ther. 1997; 20:30–40. [PubMed: 9004120]
68. Ianuzzi A, Khalsa PS. Comparison of human lumbar facet joint capsule strains during simulated high-velocity, low-amplitude spinal manipulation versus physiological motions. Spine J. 2005; 5:277–290. [PubMed: 15863084]
69. Ianuzzi A, Pickar JG, Khalsa PS. Determination of torque-limits for human and cat lumbar spine specimens during displacement-controlled physiological motions. Spine J. 2009; 9:77–86. [PubMed: 17983845]
70. Ianuzzi A, Pickar JG, Khalsa PS. Validation of the cat as a model for the human lumbar spine during simulated high-velocity, low-amplitude spinal manipulation. J Biomech Eng. 2010; 132:071008. [PubMed: 20590286]
71. Henderson CN, Cramer GD, Zhang Q, DeVocht JW, Fournier JT. Introducing the external link model for studying spine fixation and misalignment: part 2, Biomechanical features. J Manipulative Physiol Ther. 2007; 30:279–294. [PubMed: 17509437]
72. Lee M, Liversidge K. Posteroanterior stiffness at three locations in the lumbar spine. J Manipulative Physiol Ther. 1994; 17:511–516. [PubMed: 7836873]
73. Viner A, Lee M, Adams R. Posteroanterior stiffness in the lumbosacral spine, The correlation between adjacent vertebral levels. Spine. 1997; 22:2724–2730. [PubMed: 9431605]
74. Colloca CJ, Keller TS, Black P, Normand MC, Harrison DE, Harrison DD. Comparison of mechanical force of manually assisted chiropractic adjusting instruments. J Manipulative Physiol Ther. 2005 Jul.28:414–422. [PubMed: 16096041]
75. Murphy, DR.; Morris, C. Manual examination of the patient. In: Haldeman, S.; Dagenais, S., editors. Principles and practice of chiropractic. 3rd ed. New York: McGraw-Hill, Medical Pub. Division; 2005. p. 593-610.

Practical Applications

This study found that intervertebral dysfunction at a single facet joint can alter paraspinal sensory input from mechanoreceptors during clinically relevant durations of HVLA-SM.

This may become important to patient care if future studies show that a critical threshold of paraspinal sensory input is required to obtain positive clinical outcomes.

Findings are limited to simulated dorsal-ventral HVLA-SM manipulative thrust in otherwise healthy animals. Confounding factors such as degenerative and/or inflammatory joint changes as well as rotary thrust components such as common in clinical settings may alter these findings.

Figure 1.

Photos showing the $L_{5/6}$ facet-fixation with the facet screw (A), forceps rigidly attached to the L_6 spinous process (B), and the cut L_6 dorsal nerve rootlets (C) along with an x-ray showing an inserted $L_{5/6}$ facet-screw (D), and a $L_{5/6}$ facetectomy (E).

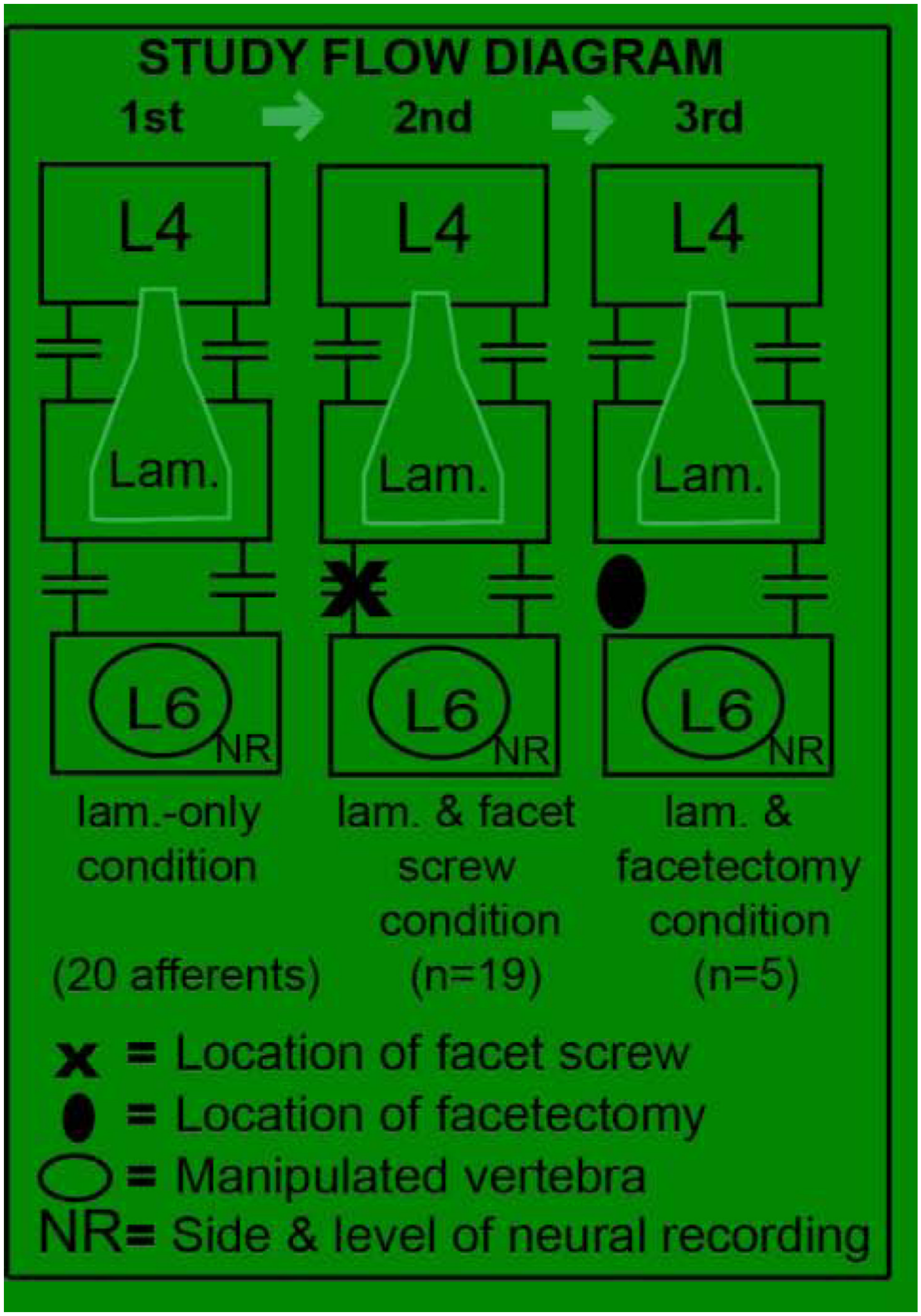

Figure 2.

Diagram showing the anatomical location and sequence of surgical procedures (laminectomy-only, laminectomy & facet screw condition, and laminectomy & facetectomy condition) performed in the same animal while maintaining a primary afferent recording. Lam. represents the extent of surgical laminectomy performed; NR, neural recording; n = number of comparisons made to laminectomy-only condition that met the inclusion criteria.

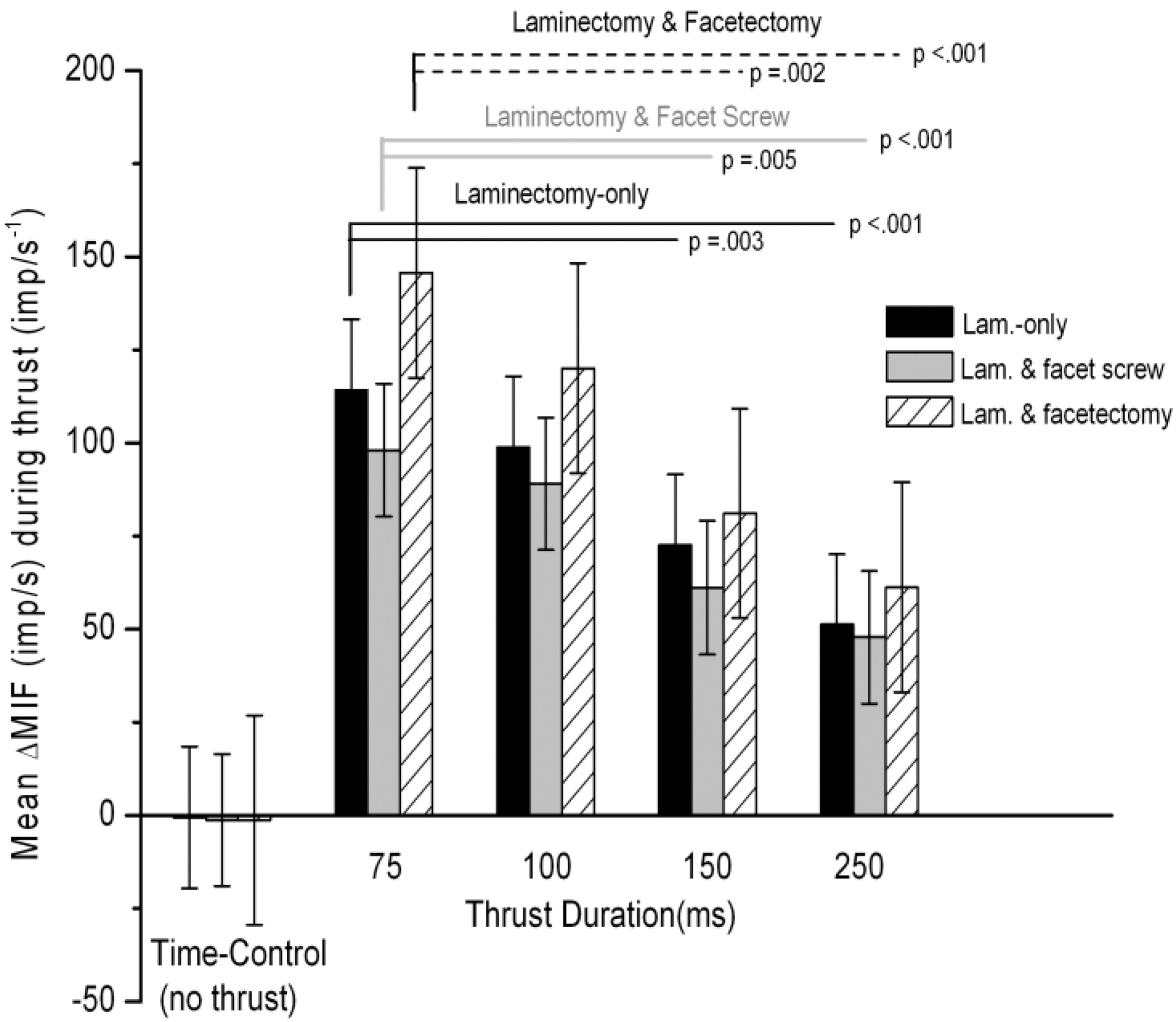

Figure 3.

Comparisons between mean change in mean instantaneous frequency (ΔMIF) during five manipulative thrust durations applied in each of three spinal joint conditions. Time-control represents a non-thrust or 0 ms thrust duration. Data reported as adjusted means and 95% confidence intervals with significance. Lam.= laminectomy.

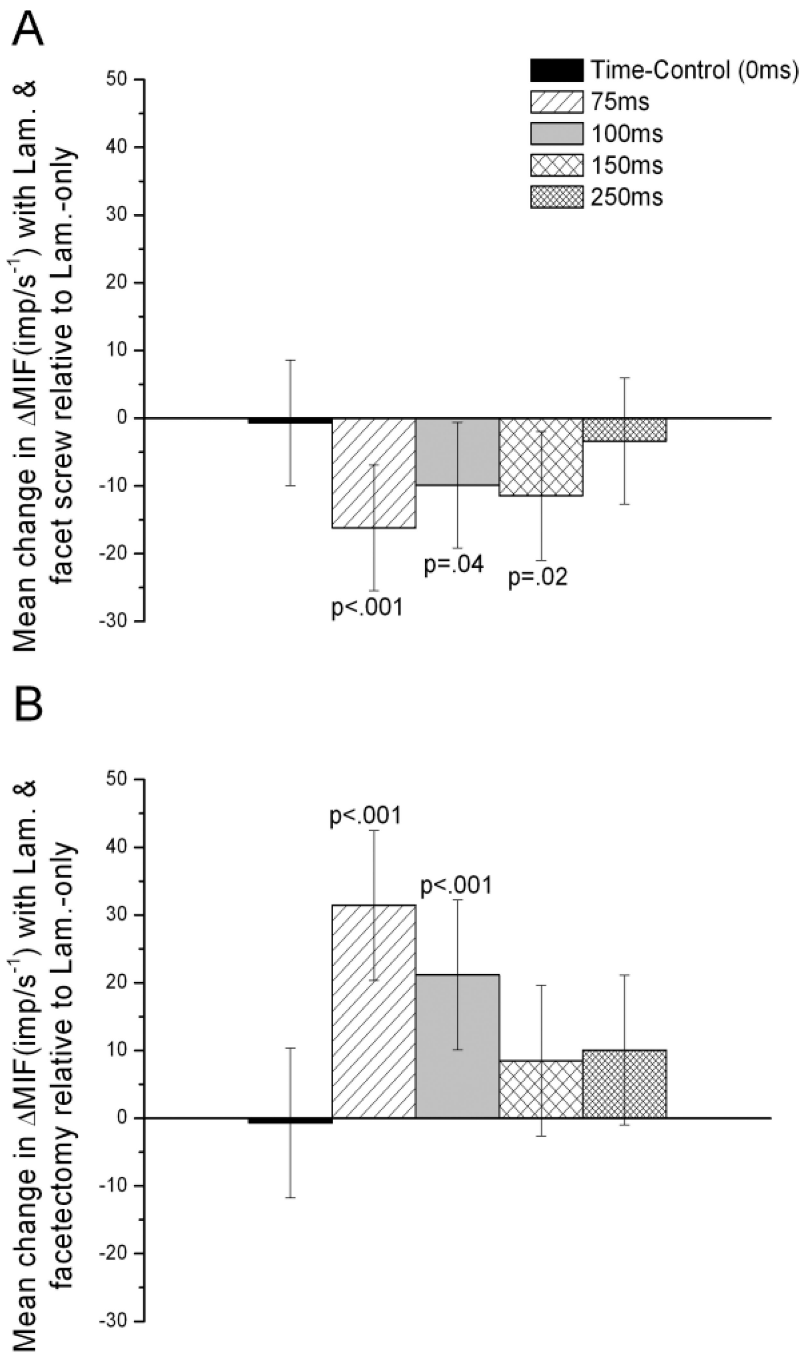

Figure 4.
Comparisons of the mean change in mean instantaneous frequency (ΔMIF) during five manipulative thrust durations between the laminectomy-only and the laminectomy & facet screw conditions (A) and the laminectomy-only and the laminectomy & facetectomy conditions (B). Data reported as adjusted means and 95% confidence intervals. Time-control represents a non-thrust or 0 ms thrust duration. Lam.= laminectomy.