Three-Dimensional Vertebral Motions Produced by Mechanical Force Spinal Manipulation

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Abstract

Objective: The aim of this study was to quantify and compare the 3-dimensional intersegmental motion responses produced by 3 commonly used chiropractic adjusting instruments.

Methods: Six adolescent Merino sheep were examined at the Institute for Medical and Veterinary Science, Adelaide, Australia. In all animals, triaxial accelerometers were attached to intraosseous pins rigidly fixed to the L1 and L2 spinous processes under fluoroscopic guidance. Three handheld mechanical force chiropractic adjusting instruments (Chiropractic Adjusting Tool [CAT], Activator Adjusting Instrument IV [Activator IV], and the Impulse Adjusting Instrument [Impulse]) were used to randomly apply posteroanterior (PA) spinal manipulative thrusts to the spinous process of T12. Three force settings (low, medium, and high) and a fourth setting (Activator IV only) were applied in a randomized repeated measures design. Acceleration responses in adjacent segments (L1 and L2) were recorded at 5 kHz. The multiaxial intersegmental (L1-L2) acceleration and displacement response at each force setting was computed and compared among the 3 devices using a repeated measures analysis of variance (α = .05).

Results: For all devices, intersegmental motion responses were greatest for axial, followed by PA and medial-lateral (ML) measurement axes for the data examined. Displacements ranged from 0.11 mm (ML axis, Activator IV low setting) to 1.76 mm (PA axis, Impulse high setting). Compared with the mechanical (spring) adjusting instruments (CAT, Activator IV), the electromechanical Impulse produced the most linear increase in both force and intersegmental motion response and resulted in the greatest acceleration and displacement responses (high setting). Significantly larger magnitude intersegmental motion responses were observed for Activator IV vs CAT at the medium and high settings ($P < .05$). Significantly larger-magnitude PA intersegmental acceleration and displacement responses were consistently observed for Impulse compared with Activator IV and CAT for the high force setting ($P < .05$).

Conclusions: Larger-magnitude, 3D intersegmental displacement and acceleration responses were observed for spinal manipulative thrusts delivered with Impulse at most force settings and always at the high force setting. Our results indicate that the force-time characteristics of impulsive-type adjusting instruments significantly affects spinal motion and suggests that instruments can and should be tuned to provide optimal force delivery. (J Manipulative Physiol Ther 2006;29:425-436)

Key Indexing Terms: *Biomechanics; Chiropractic; Manipulation, Spinal; Spine; Mechanical Force*

Spinal manipulation is the most commonly performed therapeutic procedure provided by doctors of chiropractic.[1] Likewise, chiropractic techniques have evolved, providing clinicians with choices in the delivery of particular force-time profiles deemed appropriate for a particular patient or condition. Clinicians often rely upon mechanical advantages in performing spinal manipulation through patient positioning and mechanical assistance

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from a table or handheld adjusting instrument.[2] Specifically, manual articular manipulative and adjusting procedures have been classified into 4 categories to better describe the technique and mechanism of force production: specific contact thrust procedures (ie, high-velocity, low-amplitude [HVLA] thrusts), nonspecific contact thrust procedures (ie, mobilization), manual force, mechanically assisted procedures (ie, drop tables or flexion-distraction tables), and mechanical force, manually assisted (MFMA) procedures (ie, stationary or handheld instruments).[3] Today, MFMA procedures are reported to be the second most popular chiropractic adjusting technique used by 72% of chiropractors on 21% of their patients.[4]

Spinal manipulative techniques have been studied for their clinical effectiveness.[5,6] Most randomized controlled clinical trials in patients with low back pain, neck pain, and headache[7-12] have been conducted using HVLA thrusts, which are inherently dynamic in nature. Recently, studies have also begun to compare HVLA to MFMA procedures with equivocal findings reported.[13-15] Hence, although clinical outcome studies have gained attention, basic experimental science is lacking, which might assist in explaining biomechanical mechanisms.[16] Evidence that putative mechanisms might be related to the dynamic mechanical excitation characteristics of HVLA and MFMA procedures is growing.[17-22] Some authors have hypothesized that mechanisms may be related to the oscillatory or vibration response induced by dynamic mechanical excitation of the spinal structures.[22-24] Quantifying the dynamic biomechanical characteristics of chiropractic technique application is therefore a logical and important first step in understanding a spinal manipulative procedure.

Several studies have investigated the forces produced during a variety of spinal manipulative procedures, including HVLA and MFMA procedures.[25-32] Others have quantified segmental and intersegmental vertebral displacements, velocity, and acceleration responses to mechanical force spinal manipulation.[33-36] These studies have assisted in the development of mathematical models to predict vertebral kinematic responses to specific spinal manipulative force-time profiles and vectors.[24,37] Mathematical models and recent animal studies[38] have also shown that external mechanical forces applied at or near the natural frequency of the spine (5-40 Hz) are associated with appreciably greater displacements (>2-fold), in comparison with external forces that are static or quasistatic, whereas higher frequencies (typically >50 Hz) are attenuated by the spine.

Mechanical force, manually assisted procedures are typically characterized as impulsive. Mechanical forces that are relatively large in magnitude but act for a very short time (much less than the natural period of oscillation of the structure), are called "impulsive."[26] Impulsive forces acting on a mass (eg, spine) will result in a sudden change in velocity but are typically associated with smaller amplitude displacements, in comparison with longer duration forces. However, the sudden change in velocity associated with impulsive forces causes the spine to oscillate or vibrate for long periods.[22] Structures that are mechanically excited with a haversine (half sine) pulse-time profile experience more uniform excitation frequency.[38] Several spinal manipulative instruments have been developed to take advantage of desired benefits of impulsive haversine-like force-time inputs.

A popular handheld spinal manipulation device, the Activator Adjusting Instrument (Activator Methods International, Ltd, Phoenix, Ariz) underwent several modifications to improve its frequency area ratio (measure of the amount of energy delivered over a specific frequency range) and subsequently marketed as the Activator II, Activator III, and the latest version, Activator IV.[39,40] A recent biomechanical study that performed bench comparisons of 4 spring-activated devices (Activator Adjusting Instrument; Activator Adjusting Instrument II; Activator Adjusting Instrument III; and Activator Adjusting Instrument IV [Activator IV]), and 2 electromechanical devices (Harrison Handheld Adjusting Instrument and Neuromechanical Impulse Adjusting Instrument) noted substantial improvements in the frequency area ratio of the electromechanical instruments compared with the spring-activated devices.[20] Presumably, mechanical devices that stimulate a broad range of vibration frequencies within the spine have the potential to elicit neurophysiological responses.[18,19,41] Validation of these findings in humans and animals has not been conducted.

Knowledge of the effects of transmitted forces on intersegmental motion during chiropractic adjustment/spinal manipulation is important in validating spine models and assessing the biomechanical characteristics of chiropractic treatments and assists in understanding treatment efficacy and assessment of risk in the medicolegal arena. The purpose of this study was to quantify and compare the multiaxial spinal acceleration and displacement responses produced by 3 commonly used MFMA chiropractic adjusting instruments.

Methods

Six adolescent Merino sheep (mean, 49.7 kg; SD, 6.4) served as subjects for the study. The research protocol was approved by the Animal Ethics Committees and Institutional Review Board of the Institute of Medical and Veterinary Science (Adelaide, South Australia). After anesthesia, the animals were placed in a standardized prone-lying position with the abdomen and thorax supported by a rigid wooden platform and foam padding, respectively, thereby positioning the lumbar spine parallel to the operating table and load frame.

After animal preparation, 10-g piezoelectric triaxial accelerometers (Crossbow Model CXL10HF3; Crossbow Technology, Inc, San Jose, Calif) were attached to intraosseous pins that were rigidly fixed to the L1 and L2 lumbar spinous processes under fluoroscopic guidance (Fig 1). The accelerometers are high-frequency vibration measurement devices composed of an advanced piezoelectric material integrated with signal conditioning (charge amplifier) and current regulation electronics. The sensors feature low noise (300-μg rms), wide bandwidth (0.3-10 000 Hz), and low nonlinearity (<1% of full scale) and are precision-calibrated by the manufacturer. The x-, y- and z-axes of the accelerometer were oriented with respect to the medial-lateral (ML), posterior-anterior (PA), and cranial-caudal or axial (AX) axes of the vertebrae. The in situ natural frequency of the pin and transducer was determined intraoperatively by "tapping" the pins in the ML, PA, and AX axes and was found to be greater than 80 Hz. Tapping the pin (using the edge of a scalpel handle) served to verify that the pin was rigidly attached to the bone—a loose pin showed as a reduction in the vibration frequency.

Three handheld MFMA chiropractic adjusting instruments were used to apply posteroanterior (PA) spinal manipulative thrusts to the T12 spinous process of the ovine spine: Activator IV (Activator Methods International), a chiropractic adjusting tool (CAT; J-Tech Medical Industries, Salt Lake City, Utah), and an Impulse Adjusting Instrument (Impulse; Neuromechanical Innovations, LLC, Phoenix, Ariz) (Fig 2). Specifically, the neoprene end member of the stylus of each device was placed on the spinous process of T12 and held perpendicularly with a preload of approximately 20 N. The T12 spinous process was located by palpation as the first spinous process cephalad to the fluoroscopically verified L1 vertebra containing the pin mount. Five mechanical excitation tests were performed for each of 3 instrument force settings (low, medium, and high) and a fourth setting (Activator IV only). Each of the spinal manipulative protocols was performed in a randomly determined order. A doctor of chiropractic with 10 years of clinical experience and familiarity with each of the instruments administered spinal manipulative thrusts. The applied preload, force-time profiles, and impulsive force magnitudes of the 3 instruments were previously measured using a dynamic bench-top load measuring system.[20]

Using a previously published method,[19,35] L1 and L2 vertebral accelerations were recorded at a data sampling frequency of 5000 Hz using a 16-channel, 16-bit MP150 data acquisition system (Biopac Systems, Inc, Goleta, Calif). The sampling period (0.2 milliseconds) was an order of magnitude greater than the impulse force pulse duration, and the sampling frequency was nearly 2 orders of magnitude greater than the natural frequency of the pin-accelerometer-bone mount, which ensured that the spinal manipulation therapy–induced vertebral oscillations were captured with appropriate signal bandwidth. Displacement-time responses were obtained from the acceleration time histories using trapezoidal numerical integration (Matlab, MathWorks, Boston, Mass). Peak-to-peak magnitudes of the

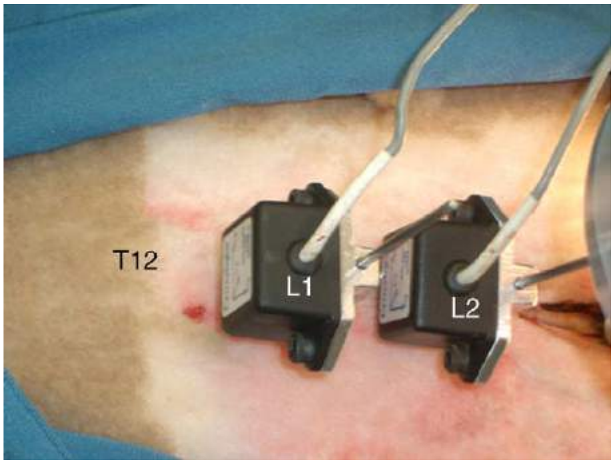


Fig 1. *Experimental setup depicting the triaxial accelerometers attached to pins inserted into the L1 and L2 spinous processes of the ovine spine.*

ML, PA, and AX vertebral acceleration and displacement time histories were computed using Matlab. For statistical purposes, only peak-to-peak acceleration and displacement responses are considered in this study. Intervertebral or intersegmental (L1-L2) displacement time and acceleration time histories were obtained by taking the difference of the L1 and L2 displacement time and acceleration time histories, respectively. Peak-peak intersegmental accelerations and displacements were subsequently computed for each accelerometer axis (ML, AX, and PA).

Statistical comparisons for device-specific, peak-peak intersegmental acceleration and displacement at low, medium, high and fourth (Activator IV vs CAT high and Impulse high) settings were assessed using a repeated measures analysis of variance ($P < .05$, significant difference). Descriptive statistics, including mean and SD of the peak-peak accelerations and displacements were performed using Microsoft Excel (Microsoft Corporation, Inc, Redmond, Wash).

Results

The force-time characteristics of the Activator IV and Impulse instruments have been previously reported[20] but are presented here (in part) along with results for the CAT instrument so that the 3D motion response of the instruments can be considered in context with device force specifications. Both of the mechanically (spring) activated devices (Activator IV, CAT) produced rapidly changing, oscillatory force-time waveforms, approximately 5 milliseconds in duration. The electromechanical Impulse instrument produced a single haversine force-time waveform with a shorter duration pulse of approximately 2 milliseconds. Impulse produced the highest force (high setting), whereas the Activator IV produced the lowest force (low setting). All

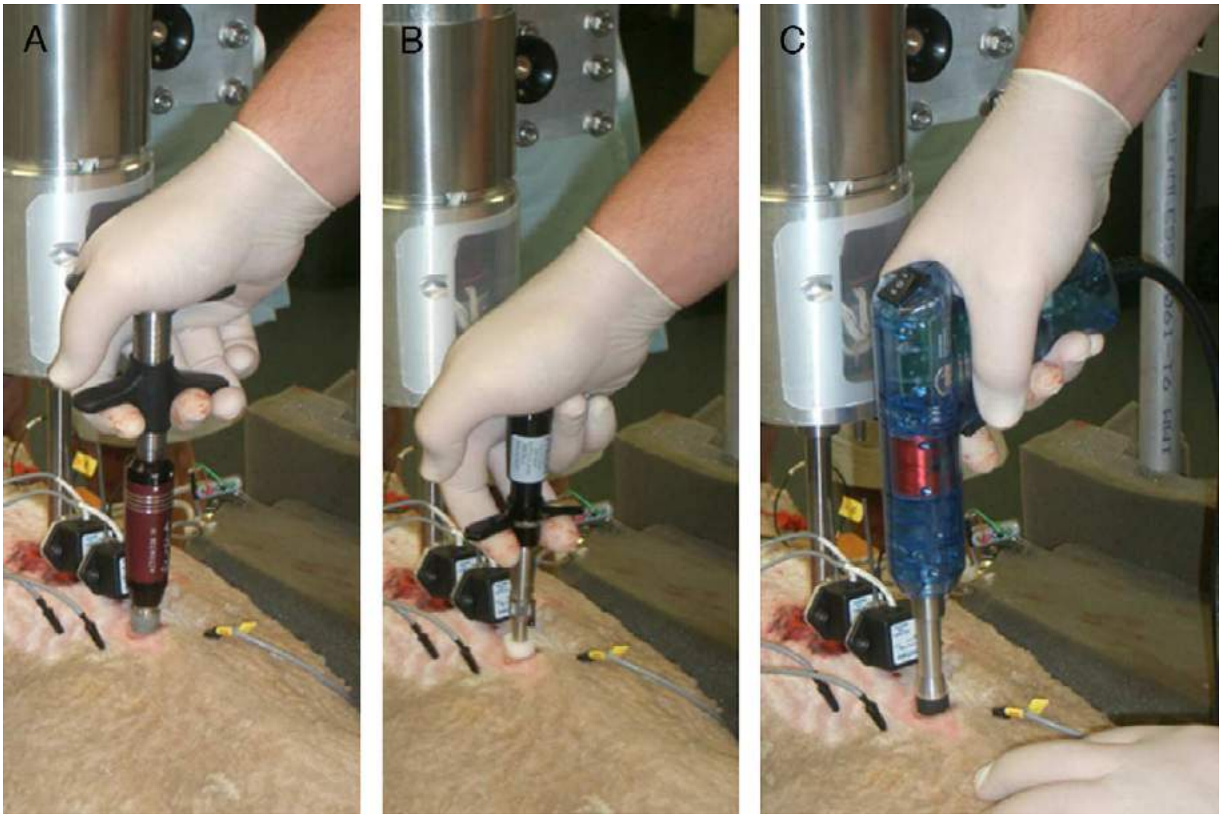


Fig 2. *The Activator IV (A), CAT (B), and Impulse (C) adjusting instruments are each shown in the experimental setup contacting the spinous process of T12. Triaxial accelerometers mounted to bone pins rigidly fixed in the spinous processes of L1 and L2 for intersegmental acceleration measurement. The wires on either side of the adjusting instruments are bipolar electromyography electrodes, which are used as outcome measures in conjunction with other objectives of the research.*

3 instruments had roughly equivalent forces for the lowest force setting. The Activator IV instrument showed very little force variation for 3 of the 4 force settings. Only the Impulse produced a linear increase in peak force with increasing force setting. Peak forces for the 3 instruments are summarized in Table 1.

After the application of MFMA instrument adjusting mechanical excitation at T12, the L1-L2 ovine spine oscillated for a period of approximately 160 milliseconds (Fig 3). Peak-peak intersegmental (L1-L2) acceleration and displacement responses for the 3 adjusting instruments at each axis are summarized in Figures 4-6. L1-L2 accelerations were greatest for AX, followed by PA and ML sensor measurement axes, whereas L1-L2 displacements were greatest for PA, followed by AX and ML sensor axes. The greatest peak-peak ML (mean, 0.22; SD, 0.12 mm), PA (mean, 1.76; SD, 1.55 mm), and AX (mean, 0.94; SD, 0.37 mm) displacements were observed for the Impulse instrument (high setting). Acceleration and displacement responses tended to mirror the peak force produced by each instrument, that is, the Impulse resulted in a relatively linear increase in PA, ML, and AX acceleration and displacement with increasing force setting, whereas the Activator IV device tended to produce roughly equivalent PA, ML, and AX accelerations and displacements for the medium and high force settings. The peak-peak intersegmental displacements in the ML, PA, and AX axes tended to mirror the acceleration responses for all force settings.

Table 1. *Device comparisons for peak force (Newtons) at low, medium, and high instrument settings*

Force setting	Activator IV	CAT	Impulse
L	123.1 (2.2)	130.9 (6.7)	132.5 (26.9)
M	121.0 (2.7)	237.1 (21.0)	245.0 (7.8)
H	114.9 (6.7)	287.0 (23.8)	380.2 (14.1)
4[a]	211.6 (8.6)	NA	NA

Mean values (SDs) for 10 thrusts at each force setting. *L*, Low; *M*, medium; *H*, high.
[a] Setting available for Activator IV only.

Statistical comparison (*P* values, repeated measures analysis of variance) of the intersegmental acceleration and displacement responses for the Activator IV, CAT, and Impulse devices are summarized in Tables 2 and 3. Significantly larger-magnitude L1-L2 accelerations (AX,

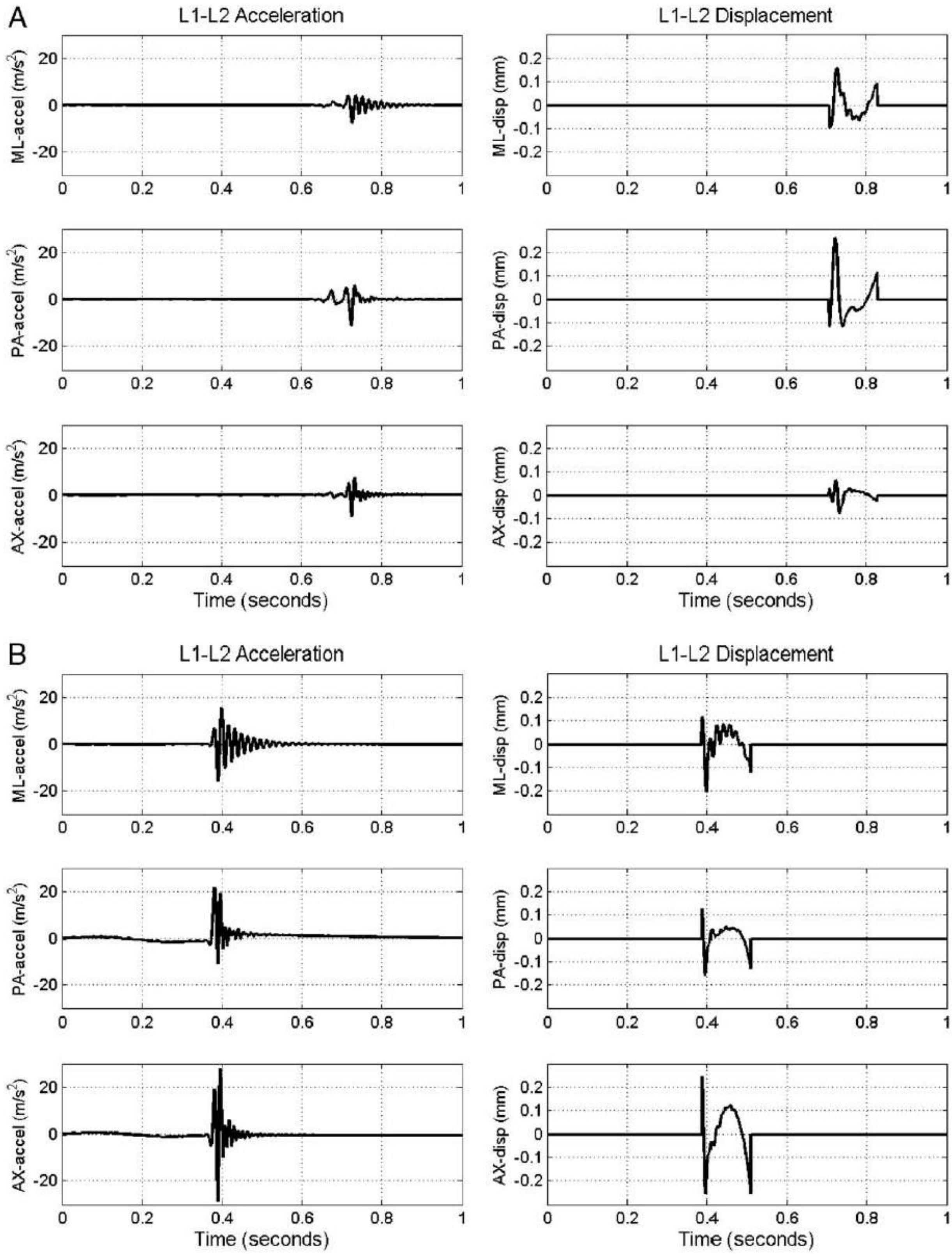


Fig 3. *Typical (animal 016) intersegmental (L1-L2) ML, PA, and AX acceleration and displacement time histories obtained during medium force setting mechanical excitation using the Activator IV (A, top) and Impulse (B, bottom) adjusting instruments.*

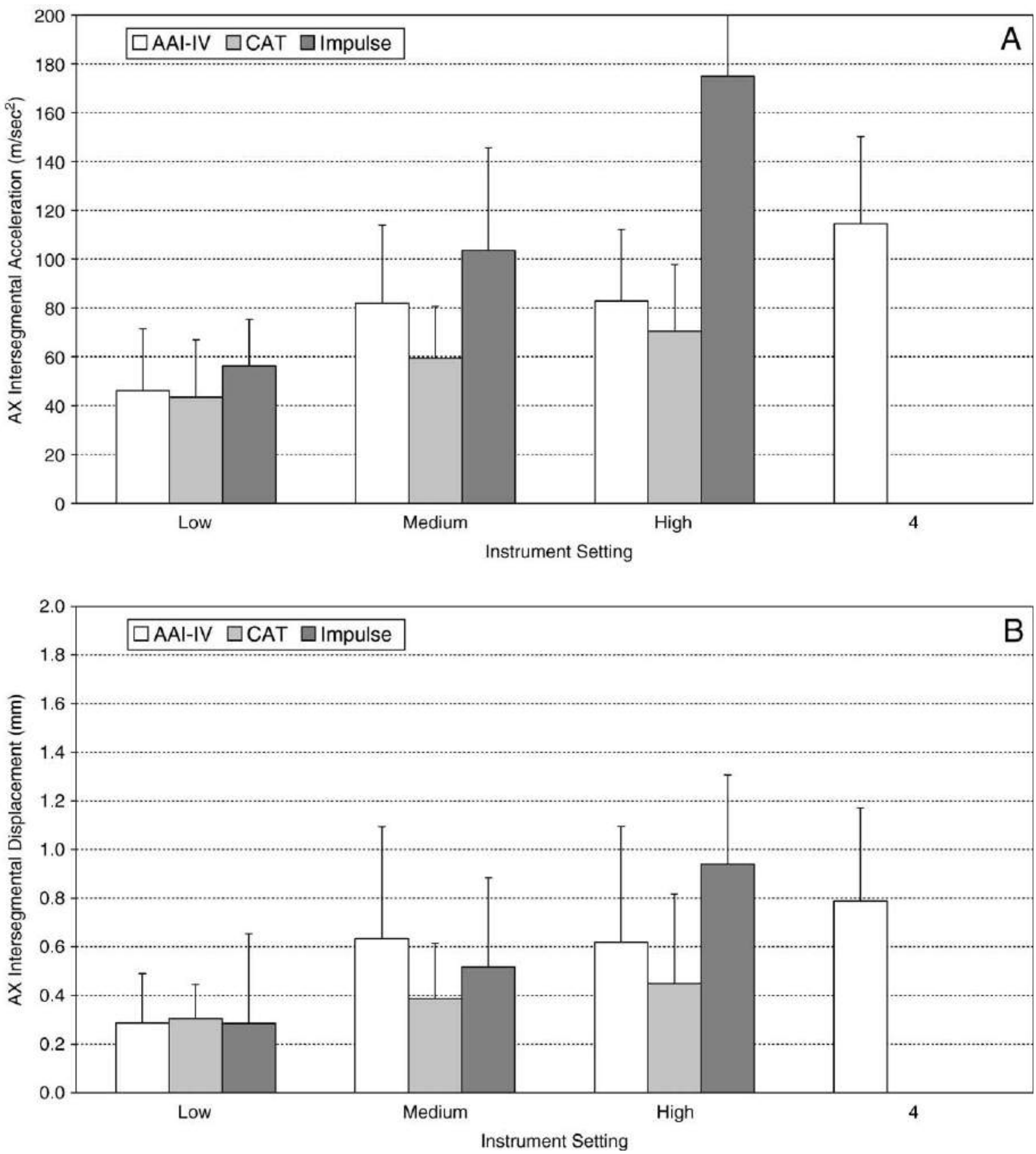
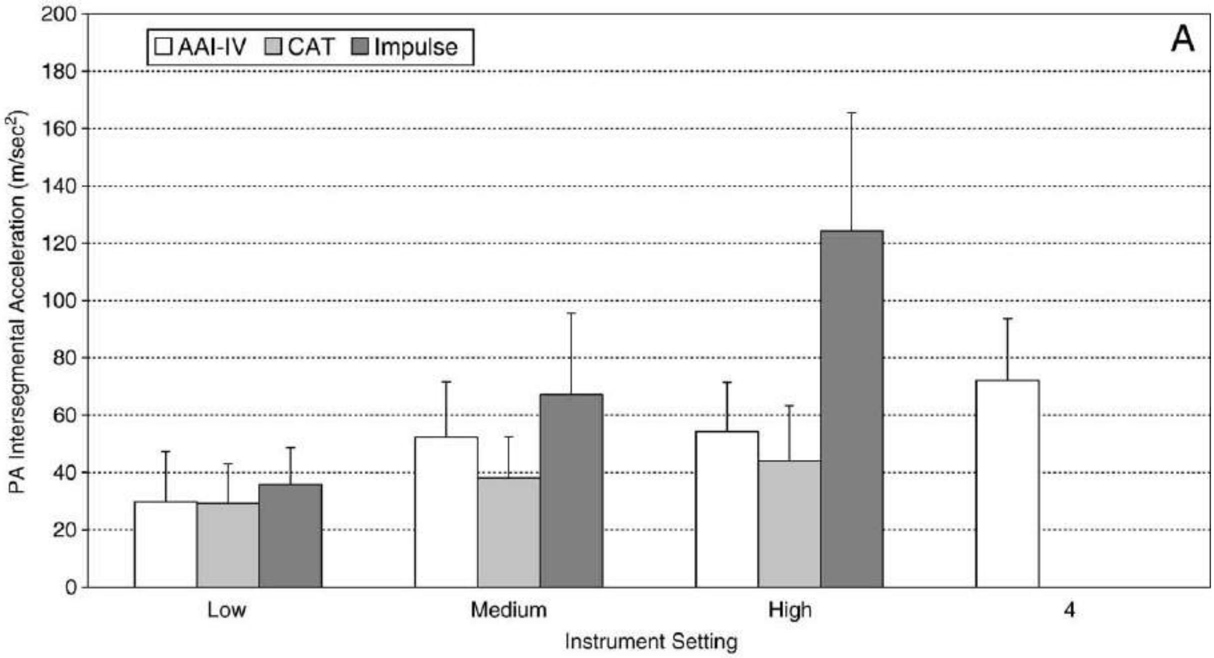


Fig 4. *Peak-peak axial (AX) intersegmental (L1-L2) acceleration (A, top) and displacement (B, bottom) responses to posteroanterior (PA) impulsive forces delivered to the T12 spinous process of 6 adolescent sheep. Bars represent mean values (error bars are SD) for each instrument force setting. Statistical comparisons of the data are summarized in Tables 2 and 3.*

PA, and ML) and displacements (AX and PA) were observed for Activator IV in comparison with CAT at the medium setting and setting 4 ($P < .05$). Significantly lower-magnitude AX, PA, and ML L1-L2 acceleration responses were consistently observed for the spring-activated instruments (Activator IV, CAT) vs the electromechanical instrument (Impulse) for most medium and high force settings examined ($P < .05$), differences measuring nearly 2- to 3-fold larger in some cases. Posteroanterior and ML displacement responses, however, tended to be higher for Activator IV and CAT vs Impulse for the low and medium force settings examined ($P < .05$), whereas the opposite was observed at the high force setting. Compared with the Activator IV setting 4 (highest), the high force settings on the Impulse device produced significantly greater ($P < .05$) AX and PA accelerations and PA displacements.



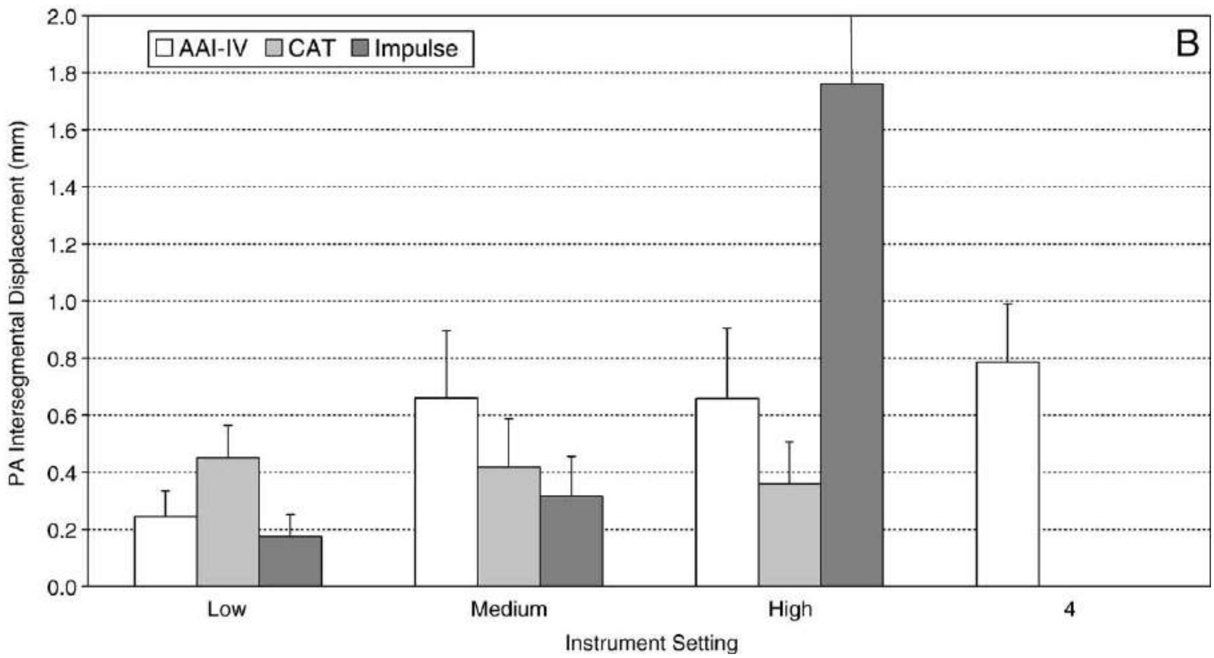


Fig 5. *Peak-peak PA intersegmental (L1-L2) acceleration (A, top) and displacement (B, bottom) responses to posteroanterior (PA) impulsive forces delivered to the T12 spinous process of 6 adolescent sheep. Bars represent mean values (error bars are SD) for each instrument force setting. Statistical comparisons of the data are summarized in Tables 2 and 3.*

Discussion

Differences in the acceleration and displacement responses produced by the 3 adjusting instruments examined in this study most likely reflect the force-time characteristics of the devices, namely, the pulse duration, pulse profile (impulse wave shape), and peak force. As expected, axial (flexion-extension), and PA motion were largest, whereas ML motions were substantially lower. This finding reflects that the impulsive forces were applied to the sheep spinous processes in an anteroposterior (dorsoventral) direction. Differences in spinal motions occur when contacting on the spinous processes, as opposed to the transverse processes,[35] and significantly larger ML motions would have been expected to occur had we contacted over

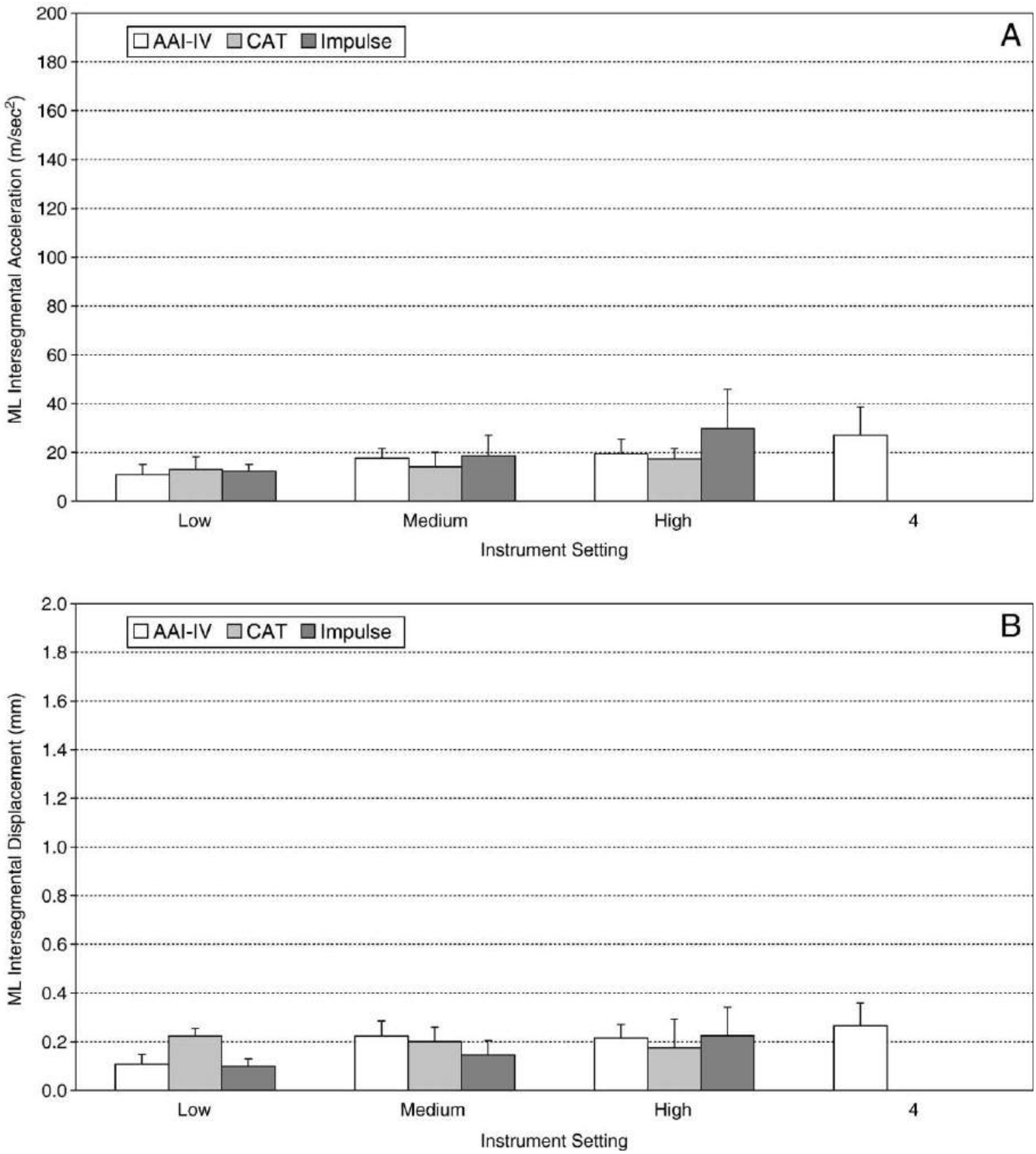


Fig 6. *Peak-peak ML intersegmental (L1-L2) acceleration (A, top) and displacement (B, bottom) responses to PA impulsive forces delivered to the T12 spinous process of 6 adolescent sheep. Bars represent mean values (error bars are SD) for each instrument force setting. Statistical comparisons of the data are summarized in Tables 2 and 3.*

the transverse processes. However, ML motion responses are expected because of spinal coupling[35] and/or sagittal plane offset associated with the mechanical excitation.

To understand the biomechanical consequences of chiropractic adjustment/spinal manipulation more fully, chiropractic researchers are currently focusing on quantifying the applied forces associated with spinal manipulation and mechanical response of the spine to these forces.[2,23,25,26,29,31,42] Basic experiments to quantify the intersegmental motion responses occurring during mechanical force spinal manipulation, as presented in the current study, are important first steps in understanding the biomechanics of spinal manipulation. The current study is the first to present intersegmental spinal motions (acceleration or vibration and vertebral displacement) occurring during known mechanical force spinal manipulation

Table 2. *Device comparisons (P values) for intersegmental acceleration at low, medium, and high instrument settings*

Intersegmental (L1-L2) acceleration axis	Force setting	Activator IV vs CAT	Activator IV vs Impulse	CAT vs Impulse
AX	L	.685	.110	**.035**↓
	M	**.004**↑ [a]	**.040**↓	**<.001**↓
	H	.122	**<.001**↓	**<.001**↓
	4[b]	**<.001**↑	**<.001**↓	NA
PA	L	.906	.158	.078
	M	**.004**↑	**.032**↓	**<.001**↓
	H	**.047**↑	**<.001**↓	**<.001**↓
	4[b]	**<.001**↑	**<.001**↓	NA
ML	L	.095	.198	.434
	M	**.011**↑	.619	**.028**↓
	H	.127	**.003**↓	**<0.001**↓
	4[b]	**<.001**↑	.458	NA

P values in bold are statistically significant. Arrows indicate relative increase or decrease compared with second comparison device.

[a] ↑ Indicates Activator IV produced greater intersegmental acceleration in comparison with CAT at this force setting.

[b] Compared with H setting.

Table 3. *Device comparisons (P values) for intersegmental displacement at low (L), medium (M) and high (H) instrument settings*

Intersegmental (L1-L2) displacement axis	Force setting	Activator IV vs CAT	Activator IV vs impulse	CAT vs impulse
AX	L	.714	.994	.656
	M	**.019**↑ [a]	.250	**.045**↓
	H	.125	**.009**↓	**<.001**↓
	4[b]	**<.001**↑	.153	NA
PA	L	**<.001**↓	**.004**↑	**<.001**↑
	M	**<.001**↑	**<.001**↑	**.021**↑
	H	**<.001**↑	**<.001**↓	**<.001**↓
	4[b]	**<.001**↑	**.001**↓	NA
ML	L	**<.001**↓	.344	**<.001**↑
	M	.164	**<.001**↑	**.002**↑
	H	**.002**↑	.702	**.038**↓
	4[b]	**<.001**↑	.174	NA

P values in bold are statistically significant. Arrows indicate relative increase or decrease compared with second comparison device.

[a] ↑ Indicates Activator IV produced greater intersegmental displacement in comparison with CAT at this force setting.

[b] Compared with H setting.

devices. Intersegmental motion responses provide important information regarding the relative motion of the sheep lumbar spine motion segment. Indeed, dynamic computer models[24,37] indicate that the intersegmental motion response (acceleration, displacement) of the spine subjected to impulsive, oscillatory, and static loading is more similar under these loading conditions than segmental motions, which was the motivation for reporting intersegmental acceleration responses in the current study. In addition, studies have shown that mechanical stimulation using force-time profiles with a short pulse duration produces greater segmental and intersegmental acceleration and displacement responses, which are most likely due to the abrupt change in loading and unloading of the spine.[21,43] The Impulse also produces a more haversine wave shape in comparison with spring-activated devices, which creates a more efficient dynamic force transfer to the spine.[20]

Two of the instruments examined in this study were mechanically (spring) activated devices that produce a force-time pulse duration of approximately 5 milliseconds. In contrast, the Impulse device is a microprocessor-controlled electromechanical adjusting instrument that produces a shorter duration force-time pulse (approximately 2 milliseconds). In this study, the Impulse was found to produce the largest intersegmental motion responses (acceleration and displacement), in comparison with the mechanical spring-loaded Activator IV and CAT instruments, which most likely reflects the larger range of forces produced by this device. Thus, the Impulse offers clinicians a wider selection and range of peak forces and concomitant larger intersegmental spinal motions for MFMA chiropractic adjustment/spinal manipulation. Each of the mechanical force spinal manipulation devices examined in this study delivers forces over a very short time interval (<5 milliseconds for Activator IV and CAT; <2 milliseconds for Impulse) as opposed to HVLA spinal manipulation ($\approx$150 milliseconds time interval), which results in much lower force impulse and segmental motion imparted to the spine. These differences, together with articular cavitation, vertebral movements, and spinal neuromuscular reflex responses represent important biomechanical considerations when studying different forms of chiropractic adjustment/spinal manipulation.[18,25,44,45]

As noted previously, each of the chiropractic adjusting instruments examined in this study produced relatively large-amplitude (maximum setting) force-time histories with primarily peak pulse durations less than 0.005 seconds. Forces that are relatively large in magnitude, but act for a very short time (much less than the natural period of oscillation of the structure), are called "impulsive."[26] Impulsive forces acting on a mass will result in a sudden change in velocity but are typically associated with smaller amplitude displacements, in comparison with longer duration forces. However, the manner in which the structure (eg, the spine) is mechanically excited will depend on the frequency content of the instrument's force-time history, and significant displacements can be produced provided that the force-time history contains frequency components at or near the natural frequencies of oscillation of the structure. In the current study, the larger amplitude intersegmental motions observed for the electromechanical adjusting instrument (Impulse) in comparison with the spring actuated devices are most likely due to larger peak forces and/or increased frequency area ratios—a measure of the overall frequency content or relative frequency distribution of the impulsive force.[20] Indeed, comparison of roughly equivalent device forces (eg, setting 4 for Activator IV, setting 2 for CAT, and setting 2 for Impulse) indicated that the intersegmental acceleration responses were more equivalent. Because recent experimental studies indicate that external mechanical excitation applied at or near the natural frequency of the spine are associated with appreciably greater amplitude displacements (>2-fold) in comparison with external forces that are static or quasistatic,[24] more research is needed to optimize chiropractic interventions and treatment regimens.

The choice of an appropriate mechanical force spinal manipulation procedure should also include considerations of the failure characteristics of the elderly spine. Based on cadaveric experiments in elderly specimens (mean age, 77 years), posteroanterior failure loads of approximately 500 N (range, 200 to 727 N) were reported for the thoracic spine.[46] Their biomechanical results suggest that, although there is a reasonable margin of safety between PA failure load and forces applied during spinal manipulation, clinicians should consider the use of well-controlled, lower-force procedures such as that afforded by mechanical force spinal manipulation devices.

There are inherent limitations of this study. First and foremost, an animal model was used to study the motion response of the spine. The sheep spine is composed of structures (ligaments, bone, and intervertebral disks) that have qualitatively similar properties as the human spine[47,48] but differ in several respects, most notably geometry or morphology. Sheep lumbar vertebrae and vertebrae of other ungulates (hoofed animals) are more slender and smaller in size compared with human lumbar vertebrae. As a result, the PA stiffness of the ovine lumbar spine is substantially lower (approximately 4-fold) than the human lumbar spine.[38] However, using an animal model, we were able to perform invasive measurements of bone movement, which are otherwise difficult to perform in humans.[19,35,36]

Measurement of bone movement using intraosseous pins equipped with accelerometers[19,35,36] and other invasive motion measurement devices[49,50] has been previously shown to be a very precise measure of spine segmental motion. Moreover, the short duration (impulsive) mechanical excitation associated with the adjusting instruments produced very small displacements in the T12 and adjacent vertebrae; thus, the coordinate axes of the vertebrae and accelerometers did not change appreciably. An axial displacement change of 1 mm is estimated to produce less than a 1° change in the orientation of the accelerometers. Hence, intersegmental acceleration transfer could be estimated directly from the acceleration time recordings of the adjacent sensors. Vertebral bone acceleration measurements were obtained for vertebrae (L1, L2) adjacent to the point of force application, but we did not quantify the acceleration response of the segment under test (T12). Thus, the intersegmental motion response seen in the adjacent segments may not be representative of the response of the segment under test. However, because the spine is a highly damped, viscoelastic structure,[24] we predict that motion amplification would be even greater for the loaded segment because forces applied to that segment would not be damped by the adjacent soft tissues (ligaments, intervertebral disk, and muscle). In addition, testing was performed on anesthetized sheep, so active muscle tone was deficient during the tests. The presence of normal or hypernormal muscle tone may modulate the vibration response of the spine, so we are currently conducting impulsive force measurements while the animals are undergoing muscle stimulation. Finally, although the Impulse is equipped with a 20-N preload spring and electronic sensor, the preload applied using the other instruments was less precise. However, each device was previously calibrated using a bench-mounted load cell.[20] No load cell was used in conjunction with the test instruments, but a chiropractor proficient in the use of the instruments (CJC) performed all of the animal tests (as well as the bench calibration tests).

Conclusions

The present study presents the first comprehensive spine motion data (acceleration and displacement) for several commonly used impulsive force–type chiropractic adjusting instruments. Larger-magnitude, multiaxial intersegmental motion responses were observed for spinal manipulative thrusts delivered with the Impulse for nearly all force settings examined. Knowledge of the vertebral motion responses produced by handheld chiropractic adjusting instruments assists in understanding biomechanical responses and supports the clinical rationale for patient treatment using instrument-based adjustments. Our results indicate that the force-time characteristics of impulsive-type adjusting instruments significantly affect spinal motion and suggests that instruments can and should be tuned to provide optimal force delivery.

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