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Distribution of Cavitations as Identified with Accelerometry during Lumbar Spinal Manipulation

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Abstract

Objective—This project determined the location and distribution of cavitations (audible sounds producing vibrations) in the lumbar zygapophyseal (Z) joints that were targeted by spinal manipulative therapy (SMT).

Methods—This randomized, controlled, clinical study assessed 40 healthy subjects (20 male, 20 female), 18–30 years of age, that were block randomized into SMT (Group 1, n=30) or side-posture positioning only (Group 2, control, n=10) groups. Nine accelerometers were placed on each patient (7 on SPs/sacral tubercles of L1–S2 and 2 placed 3 cm left and right lateral to the L4/L5 interspinous space). Accelerometer recordings were made during side-posture positioning (Groups 1 and 2) and SMT (Group 1 only). The SMT was delivered by a chiropractic physician with 19 years of practice experience and included 2 high-velocity, low-amplitude thrusts delivered

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CONFLICTS OF INTEREST

No conflicts of interest were reported for this study.

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in rapid succession. Comparisons using chi-square or McNemar's test were made between number of joints cavitating from: Group 1 vs. Group 2, up-side (contact side for SMT) vs. down-side, and Z joints within the target area (L3/L4, L4/L5, L5/S1) vs. outside the target area (L1/L2, L2/L3, sacroiliac).

Results—Fifty-six cavitations were recorded from 46 joints of 40 subjects. Eight joints cavitated more than once. Group 1 joints cavitated more than Group 2 joints ($p < 0.0001$), up-side joints cavitated more than down-side joints ($p < 0.0001$), and joints inside the target area cavitated more than those outside the target area ($p < 0.01$).

Conclusions—Most cavitations (93.5%) occurred on the up-side of SMT subjects in segments within the target area (71.7%). As expected, SMT subjects cavitated more frequently than side-posture positioning only subjects (96.7% vs. 30%). Multiple cavitations from the same Z joints had not been previously reported.

Introduction

This study assessed cavitations (audible sounds producing vibrations) commonly associated with lumbar side-posture spinal manipulative therapy (SMT). Cavitations (or cavitation sounds) are theoretically associated with the therapeutic gapping of the Z joints during SMT.¹⁻³ The cavitations are thought to be the result of gas (probably carbon dioxide) entering the Z joint during the vacuum created when the joint surfaces are separated by SMT.^{4,5} More specifically, cavitations may be related to the elastic recoil of the synovial capsule away from the joint space as the gas enters the joint during the gapping caused by SMT.⁵ Brodeur speculated that the recoil of the Z joint capsule, which he associated with cavitation, stimulated capsular mechanoreceptors initiating the beneficial neurological reflex actions (decreased pain and muscle relaxation) that have been associated with SMT.⁵⁻⁸

Several studies have been performed assessing general relationships among cavitation and therapeutic outcomes. However, none of these studies determined the joints from which the cavitations originated, the studies only identified whether or not a clinician heard a cavitation during the manipulation. Teodorczyk-Injeyan found that the release of the *proinflammatory* cytokines was decreased (suppressed) in asymptomatic subjects who cavitated during thoracic SMT compared to those who did not cavitate.⁹ However, the same research group later found no significant difference between cavitation and non-cavitation SMT subjects in the release of the *immunoregulatory* cytokine IL-2, although both groups of SMT subjects showed significantly elevated levels (a positive clinical outcome) compared to controls.¹⁰

Cleland et al. studied patients with neck pain of mechanical origin who received manipulation to the thoracic region. They found no relationship among cavitations heard by the clinician during thoracic manipulation and changes in cervical pain, disability or range of motion.¹¹

Flynn and colleagues concluded that the audible release (cavitation) is not related to positive clinical outcomes (increased range of motion, decreased disability, and decreased pain) in low back pain patients.^{12,13} Bialosky et al., conducting a secondary analysis of data from a somewhat larger study, concluded cavitation during SMT was not associated with decreased perception of pain (hypoalgesia) in normal subjects undergoing thermal stimulation. However, their results were mixed because they found pain perception as measured by temporal summation (repeated painful stimulation) from the lower extremity did tend to decrease in subjects experiencing cavitation, and the authors stated the effect size of this latter finding may have been larger had more subjects been included in the study.¹⁴ The studies of Flynn et al.^{12,13} and Bialosky et al.¹⁴ used manipulative techniques designed to be

specific to the sacroiliac joints (SIJs), although their manipulative procedures most likely had some effect on the lumbar Z joints as well.

Consequently, a review of the literature indicates a need for more detailed investigation exploring the mechanism(s) and consequences of cavitation during SMT; particularly SMT designed for movement of the lumbar Z joints. Such mechanistic studies that identify the specific segments from which cavitations originate can deepen the understanding of SMT and may eventually lead to improved manual procedures.^{15–17} As stated by Protapapas and Cymet (2002): “The noises of normal and abnormal [Z] joints are built into the nature of the structures. To ignore these noises would be foolish, as they might be used to help determine the effectiveness of treatment.”¹⁸

The study reported here was designed to begin the process of addressing the current gaps of knowledge related to cavitation and SMT. Our hypotheses were that up-side Z joints during lumbar SMT would cavitate more than down-side joints and that Z joints targeted for gapping would cavitate more frequently than those outside the target area. Because there have been no previous studies simultaneously assessing the side (up-side or down-side) and specific vertebral segment cavitating during lumbar SMT, these hypotheses were based on a priori assumptions with no compelling prior evidence to support them.

New accelerometry methods were designed for this study in order to identify the specific lumbar Z joints or SIJs from which cavitations originated during lumbar side-posture SMT. Cavitations have been recorded by previous investigators;^{3,19,20} however, those studies either simply identified if a cavitation had or had not occurred^{19,20} or identified the vertebral level but not the side (i.e., not the specific joint) from which the cavitation originated.³ Advances in computing power allowed for more accelerometers to be used in this study, providing the capability of identifying the specific Z joints from which cavitations originated.

Methods

The institutional review board for human research of all participating institutions (National University of Health Sciences, Canadian Memorial Chiropractic College, Auburn University) approved this project. All subjects provided consent to participate. Forty healthy subjects between the ages of 18–30 years were recruited for this study. Because this was the first study assessing the specific location of cavitations, healthy subjects were sought in order to introduce as few confounding variables (e.g., Z joint degeneration) as possible.

Subjects responding to recruitment materials went through phone screening and a history and physical examination that applied rigorous exclusion criteria (Table 1). The inclusion and exclusion criteria were similar to those previously used in a case series (5 subjects) designed to assess the general feasibility of the methods used in this study.²¹ Subjects eligible after initial screening, including history and physical examination, were scheduled for an appointment that included an MRI scan and the accelerometry procedures.

Identification of Landmarks to Assure Proper Placement of Accelerometers

The L4 spinous process (SP) was used as the primary landmark from which all other landmarks were identified. Subjects were placed in the prone position on the MRI gantry table, the L4 SP was identified via palpation and marked with a grease pencil, a high signal MRI marker was then placed over the marked L4 SP (Figure 1a and 1b), and the subject was MRI scanned in the neutral supine position (Figure 1c). The high signal marker was readily visible on the mid-sagittal scout MRI scan (Figure 1d). The location of the high signal marker was carefully noted and used for proper placement of 9 accelerometers (see below).

Placement of 9 Accelerometers

This project used accelerometers to assess cavitations. An accelerometer is an electromechanical device (Figure 2b) that measures static or dynamic acceleration. In this study, dynamic vibration acceleration originating from the Z joints during cavitation was measured. More specifically, *piezoelectric accelerometers* were used in this project. Piezoelectricity is the ability of some materials (notably crystals and certain ceramics) to generate an electric field or electric potential (voltage) if the piezoelectric material undergoes mechanical strain (e.g., vibration). Consequently, the output (signal) of the piezoelectric accelerometers is voltage generated by the piezoelectric effect. This voltage is amplified and the signal is then read from an oscilloscope.²²

The same 2 research assistants placed the accelerometers and collected the accelerometry data throughout the study. To standardize accelerometer placement and data collection, two months of training preceded the study launch.

Following MRI scanning, subjects were placed in the prone position. The high signal marker over the L4 SP was removed. The skin indentation left by the high signal marker was used along with the scout MRI scan to accurately identify the L4 SP. Once this landmark was positively identified the accelerometers were positioned. Tape with strong adhesive characteristics was used to affix seven 1.0-cm³ accelerometers (DataTron 4507, Bruel & Kjaer, Naerum, Denmark; detailed specifications of the accelerometry data acquisition system are presented elsewhere²¹) to the spinous processes of L1–L5 and the S1 and S2 sacral tubercles. Two additional accelerometers were then positioned 3 cm left and right lateral to the L4/L5 inter-spinous space (Figure 2a–2c). The sample rate for recording from the accelerometers was 320,000 Hz, which gave an actual sample rate of 317,460 Hz per channel. Therefore a sample was taken every $1/317,460 \text{ sec} = 3.15 \times 10^{-6}$ seconds. The system allowed the origin of a cavitation to be determined within 0.4 cm, more than ample discrimination to determine the Z joint segmental level of origin (e.g., left or right L5/S1) without frequency aliasing.²¹ The arrangement of accelerometers and sampling methods allowed for assessment of cavitations from all lumbar Z joints (i.e., left and right L1/L2 – L5/S1) and also the left and right SIJs.

Randomization of Subjects

Cavitation during side-posture positioning alone was noted in a previous feasibility study.²¹ Consequently, a side-posture only (no SMT) group was included to control for the effects of the force of side-posture positioning and to determine if side-posture positioning alone would result in cavitations. The total number of subjects and the number of subjects randomized into each group were based on a power analysis using the effect sizes and data variability of the previously completed feasibility study.²¹ Subjects were randomized into 1 of 2 groups: Group 1 – side-posture SMT (n=30), and Group 2 – control group, side-posture positioning without SMT (n=10). A predetermined randomization scheme (blocked randomization) was performed prior to study initiation and randomization allocation was sealed in sequentially numbered envelopes for both males and females. All personnel were blinded to each subject's random group assignment until after the first MRI scan. When the first MRI was completed, the research assistant opened the next envelope to inform the clinician of the group into which the subject was randomized.

Subject Positioning, Spinal Manipulation, and Recording from Accelerometers

Subjects were placed on their right sides (i.e., the left side was always the up-side). This allowed for consistency in positioning for SMT and for the second MRI scan, as well as consistency in assessing cavitations from the up-side vs. down-side during SMT and side-posture positioning. When ready to initiate the final positioning and SMT, the treating

doctor of chiropractic would say “start” and the accelerometry research assistant would commence a 4-second recording from the accelerometers. The recordings included the final rotation phase of side-posture positioning (for both Groups 1 and 2) and the SMT (for Group 1 only). A LabView-based program (LabView 2009 Platform, National Instruments, Austin, Texas) tailored for this study was used to make the recordings.

A standard general manipulation, the hypothenar ilium technique,²³ was used in this study (Figure 2d). This technique positioned the patient’s up-side thigh and leg in a flexed position. The clinician palpated the interspinous spaces to determine segmental motion during thigh flexion. The amount of thigh flexion in this technique is related to the Z joint segmental level targeted for gapping, with more thigh flexion (segmental motion palpated at higher lumbar levels) being used to target higher lumbar Z joints and less flexion for lower Z joints. Thigh flexion was modulated to target the L3/L4 – L5/S1 Z joints in this study. The clinician’s “contact hand” (thrusting hand) is usually on the up-side posterior superior iliac spine; however, to avoid physical contact with accelerometers, contact in this study was on the infero-lateral (left lateral) sacrum. The clinician’s “non-contact hand” (indifferent hand) stabilized the patient’s up-side shoulder and/or chest area. The thrust through the contact was posterior-to-anterior, following the modest amount of up-side to down-side rotation induced by moving the pelvis forward while holding the shoulders stable. The intent of the procedure is to open (gap) the up-side targeted joints. The SMT was delivered by a chiropractic physician with 19 years of practice experience (SS) and included 2 high-velocity, low-amplitude thrusts delivered in rapid succession. The clinician targeted the L3/L4 – L5/S1 Z joints (subsequently referred to as the “target area”). The procedures were the same for the side-posture positioning without SMT (control) group (Group 2), except no manipulative thrust was delivered.

Following these procedures, the subjects and the SMT clinician (blinded to each other) were asked if they heard or felt a cavitation during SMT. This information was used in 1 of the 2 reliability studies (see “Reliability Studies” section, below).

Assessment of Cavitations

The presence of cavitations was assessed using a LabView program tailored to analyze the accelerometer recordings of this project. Cavitations were identified from the computer oscilloscope as shifts from the baseline of several accelerometer recordings within a short (<0.0001 sec) timeframe (Figure 3a). The specific level of cavitation (e.g., left L4/L5 or right L1/L2) was identified by the order in which the recording line for each accelerometer deviated from the baseline (Figure 3b).

Reliability Studies

Two types of reliability studies were conducted. The first was to determine the reliability of identifying cavitations from the accelerometer recordings as displayed on a computer oscilloscope, and the second was to determine the agreement between subject report, clinician report, and computer oscilloscope recordings in determining if any cavitation occurred during SMT or side-posture positioning.

Reliability Study 1: Identifying Cavitations from the Accelerometer Recordings as Displayed on the Computer Oscilloscope

Ten (10) cavitations from the project were selected using a random number generator. Two trained observers then independently viewed the LabView oscilloscope recording of each cavitation. The observers reviewed the oscilloscope’s 9 lead recordings, identified the joint from which the cavitation originated, and logged the joint onto a data sheet. The observers had 12 options for their responses for each recording (left and right L1/L2 – L5/S1 and left

and right SIJs). Each of the 2 observers (blinded to the results of one another) gave their completed data sheet to a third investigator for analysis of agreement. Weighted Kappa Coefficients (Kw) were used to assess agreement.

Reliability Study 2: Agreement Between Subject Report, Clinician Report, and Accelerometer Recordings

During the MRI and accelerometry appointment the clinician left the room immediately following the SMT (Group 1) or side-posture positioning alone (Group 2, control group) and was out of the hearing of the subject. A research assistant then separately asked both the clinician and subject if they heard and/or felt a cavitation. The clinician and subject were blinded to the answer of one another. After all subjects had completed the study, kappa coefficients (non-weighted, K) were used to assess the agreement between 1) clinician and subject, 2) clinician and interpretation of LabView accelerometer recordings, and 3) subject and interpretation of LabView accelerometer recordings.

Assessment of Cavitations

Data analyses for the 40 subjects began with identification of the locations of cavitations (i.e., identification of specific Z joints and SIJs from which cavitations originated). This information was summarized descriptively and inferential statistics were used to compare the presence/absence of cavitations, based on the oscilloscope recordings, between the following: Group 1 vs. Group 2, left side (up-side) vs. right side (down-side), target area (L3/L4, L4/L5, L5/S1) vs. non-target area (L1/L2, L2/L3, SIJ). Group 1 and Group 2 were compared using a chi-square test. Because the independence of individual joint cavitations was unknown, McNemar's test was used in conjunction with the binomial distribution to assess statistical significance for cavitations of left side vs. right side and of target vs. non-target joints.

Results

Figure 4 summarizes subject enrollment. Forty-nine (49) subjects were randomized to Group 1 or 2. Nine (9) of these were excluded immediately following the SMT or side-posture positioning for the following reasons: artifact due to vibrations caused by increased muscle tension (subject not relaxed or subtly resisting, as subjectively assessed by the treating clinician) (4 subjects); artifact due to vibrations caused by slippage of clinician's contact hand during SMT (3 subjects); or incomplete data collection (full 4-second recording not obtained due to computer memory buffer error) (2 subjects). Consequently, the initial goal of 40 subjects (Group 1 = 30, 15 males and 15 females; Group 2 = 10, 5 males and 5 females) completing the study was achieved. The means (and ranges) for age, height, and weight were 25 yrs (23–30), 67 in (60–74), and 142 lbs (94–185), respectively. No clinical differences for any of these parameters were found between subjects of Group 1 and Group 2; however, the difference in age was statistically significant because of the very tight range of ages (age: 25 vs. 26, $p=0.04$; height: 66.5 vs. 67.2, $p=0.628$; weight: 143 vs. 140, $p=0.703$). Equal numbers of males and females were randomized into each group. The ethnicity of the 40 subjects included 2 Hispanic or Latino and 38 non-Hispanics. The race of the 40 subjects was as follows: American Indian/Alaska Native = 1; Asian = 9; Black or African American = 1; White = 30 (1 subject selected 2 races).

Reliability Studies

Reliability Study 1, comparing the independent analysis of 2 observers (blinded to the results of one another) to identify cavitations from the accelerometer recordings using a computer oscilloscope found "almost perfect agreement"²⁴ ($Kw = 0.94$, Std E = 0.31). The distinct accelerometer signature and the consistency with other previously published studies

using (fewer) accelerometers^{3,21} indicated the methods were also valid. Consequently, only 1 observer (PB) was needed to analyze the oscilloscope recordings of the 40 subjects.

Reliability Study 2, agreement between subject, clinician, and LabView accelerometer recordings, found accelerometer recordings of cavitations to be in “almost perfect agreement”²⁴ with the subject (96.8%, $K=0.92$, 95%CI=0.76–1.08) and clinician (93.7%, $K=0.83$, 95%CI=0.60–1.06). The clinician and subject were also in “almost perfect agreement”²⁴ (97.5%, $K=0.91$, 95%CI=0.73–1.09). For 38 of 40 subjects all 3 sources agreed, for the remaining 2 subjects (1 in Group 1 and 1 in Group 2) the accelerometers detected nothing; however, the clinician reported cavitations in both instances and the subject reported cavitations in 1 of these instances.

Distribution of Cavitations

Fifty-six (56) cavitations were recorded from 46 joints of 40 subjects. Zero (0) to 6 cavitations were recorded from individual subjects. An unexpected finding was that 2 cavitations from the same Z joint were recorded in 7 instances (all left side, L1/L2 = 1, L2/L3 = 1, L3/L4 = 4, and L5/S1 = 1) and in 1 subject 4 cavitations were recorded from 1 joint (left L3/L4 – coincidentally, this subject was one that had 2 cavitations from another joint; therefore, 6 cavitations were identified from only 2 joints in this subject). Only 1 cavitation was counted from these multiple-cavitation joints for the descriptive and inferential analyses that follow (total = 46 cavitations).

Figure 5 and Table 2 summarize the distribution of 46 cavitations from the 40 subjects. The average cavitations/subject in Group 1 (SMT group) was 1.43 (range = 0–2) and in Group 2 (side-posture only group, control group) was 0.3 (range = 0–1).

Comparisons of Group, Side, and Target Area

Group 1 (SMT) vs. Group 2 (Side-Posture Positioning Only)—Group 1 subjects cavitated significantly more frequently than Group 2 subjects; 96.7% of Group 1 subjects cavitated (29 out of 30) vs. 30% of Group 2 subjects (3 out of 10) resulting in a difference of 66.7% (95%CI=34%–86%), which was statistically significant ($p<0.0001$).

Up-Side (Left Side) vs. Down-Side (Right Side)—Recall that the left side was the up-side for all subjects in both study groups. The up-side cavitated significantly more frequently than the down-side (93.5% vs. 6.5% of the 46 cavitations; $p<0.0001$, 95%CI=81%–98%). A sub-analysis of Group 1 found that 93% of the 43 Group 1 cavitations were on the left side vs. 7% on the right side ($p<0.0001$). The number of Group 2 cavitations ($n=3$) was not sufficient to conduct an adequate statistical analysis; however, all 3 (100%) occurred on the left side.

Target Area (L3/L4, L4/L5, L5/S1) vs. Non-Target Area (L1/L2, L2/L3, SIJ)—Cavitations occurred significantly more frequently in target area joints (71.7%, 33 of the 46 cavitations) vs. non-target area joints (28.3%, 13 of the 46 cavitations) ($p<0.01$, 95%CI for 72%=58%–85%). The results for Group 1 alone were almost identical ($p=0.005$), with 69.8% of the cavitations occurring in the target area (30 of the 43 cavitations) and 30.2% occurring in the non-target area (13 of the 43). There were insufficient cavitations in Group 2 for inferential analysis; however, all 3 Group 2 cavitations (100%) occurred in the target area.

Discussion

Summary of Results

Most cavitations (93.5%) occurred on the up-side (left side) of SMT and in the targeted segments (L3/L4, L4/L5, L5/S1 = 71.7%). As expected, subjects receiving SMT cavitated more frequently (96.7% of Group 1 subjects), although cavitations were recorded from Z joints from 30% of side-posture positioning only subjects (Group 2). In addition, 8 instances of multiple cavitations from the same Z joints were recorded. Certain factors and parameters might have influenced the results (e.g., enrollment, etc.). The following sections discuss these and other aspects of the study.

Clinical Relevance

This research is related to the theoretical model (Figure 6) that the zygapophyseal (Z) joints become hypomobile for a variety of reasons^{25,26} and that connective tissue adhesions develop in these hypomobile Z joints.²⁷ SMT separates the Z joint facet surfaces (Z joint “gapping”)²⁸ and the separation (gapping) is thought to break up the connective tissue adhesions^{25,26,29} (Figure 6). Z joint gapping has also been hypothesized to stimulate mechanoreceptors in the Z joint capsule^{30–32} that may be related to decreased pain (via a gating mechanism in the dorsal horn of the spinal cord),^{7,8,33,34} decreased muscle tension (via reflex pathways),^{6,8,35,36} and reflex changes in the autonomic nervous system.^{37–39} Other authors have hypothesized that the neural stimulation may be the genesis of reflex immunological responses as well.^{9,40,41} Z joint cavitation has been associated with Z joint gapping,^{1–5} and consequently cavitation has been associated with the putative beneficial effects of such gapping as described immediately above. Therefore, gaining a better understanding of cavitation may provide useful information to clinicians who perform SMT and researchers who study SMT.

Reliability of methods

The new accelerometry methods designed for this study were reliable and valid. We believe the 2 instances in which the clinician or both clinician and subject reported hearing cavitations when none were recorded from the accelerometers were likely due to cavitations originating from mid- to lower thoracic region Z joints that were too far superior to the L1 accelerometer to be adequately recorded by the accelerometers.

Distribution of Cavitations

The distribution of cavitations in 40 subjects was fully described in the Results. To our knowledge no other study has identified the specific segmental level and side of cavitations. In a cervical study, Reggars and Pollard identified the side of cavitation, but did not identify the segmental level of cavitation, because they used only 2 microphones (different from accelerometers, but capable of determining cavitations), 1 placed on each side of the neck immediately anterior to the transverse process of C2.¹⁹

As expected, Group 1 subjects (SMT) cavitated more than Group 2 subjects (side-posture positioning only), almost certainly because of the additional force received by the Z joints and SIJ during SMT. However, in 3 instances side-posture positioning alone caused cavitation, indicating that certain Z joints cavitate with little externally generated force. Further research assessing the biological and clinical significance of the “easily cavitating joints” may be warranted.

Consistent with our initial hypothesis, the up-side joints cavitated more frequently than those on the down-side. This, too, has not been previously reported in the lumbar region. Reggars and Pollard determined the side of cavitation in the cervical region, finding that in 94% of

the subjects the cavitation was on the same side as head and neck rotation (i.e., head and neck rotated to the right associated with cavitation on the right).¹⁹ This side of cavitation corresponds to the up-side in the lumbar study reported here, where 93.5% of cavitations were on the up-side. However, in Reggars and Pollards' cervical study the cavitation side was opposite to the side of clinician's contact during SMT (i.e., contact on the left articular pillar [Z joints] during right rotation), whereas in this lumbar region study the cavitation side was the same side as the clinician's contact. The difference may be due to the morphology of the cervical vs. lumbar Z joints. The cervical Z joints are purely planar, allowing much axial rotation, whereas the lumbar Z joints are bi-planar or curved, allowing very little rotation.⁴² Consequently, the large amount of rotation in the cervical region would tend to open (gap) the Z joints on the side of rotation, but not on the side of clinician contact. In the lumbar region, rotation is limited and the contact was not on the Z joints. As a result, the force of the SMT in this type of technique is designed to open (gap) the joints on the up-side and close the joints (lock or close-pack) the Z joints on the downside. Other studies have found that the up-side lumbar Z joints do gap (distinct from cavitation) more than the downside joints during SMT and side-posture positioning.²⁸

Another initial hypothesis was that the joints within the target area would cavitate more frequently than those outside the target area. This was found to be the case. These results indicate that although SMT is not precise,³ lumbar SMT is generally specific to a 3 vertebral segment area.

Finally, multiple cavitations from individual Z joints were recorded in 8 instances (2 cavitations in 7 instances, 4 cavitations in 1 instance). This also has never before been reported and would seem to indicate that a rapid influx of gas into the Z joint occurred more than once in the multiple cavitation joints. There are several potential reasons for the multiple cavitations. First, the technique used in this study included 2 thrusts, which likely increased the possibility of multiple cavitations. Second, the tissue resistance to gapping may have differed among Z joints and increased resistance may have caused the multiple cavitating joints to gap in more than one surge. Third, the anatomic make-up (e.g., shape) of the multiple cavitation Z joints may differ from the others. Additional research is underway to further assess the mechanisms associated with multiple cavitation joints.

Limitations

The initial phone screen exclusion rate was 18%, which is quite common for studies at our facility. The exclusion rate for the examination and MRI visits was 35%, which reflects the stringent exclusion criteria (including MRI exclusion criteria). We may have had fewer cavitations in this study if we had included wider ranges of age and weight and subjects with low back pain. However, beginning with a study designed to maximize the likelihood of recording cavitations in "normal" Z joints was determined most appropriate for the first study of this kind. More research is needed to determine the effect of age, Z joint degeneration, weight, and low back pain on cavitation.

Nine (9) subjects were excluded because of accelerometer recording artifacts (7) or incomplete data collection (2) during the side-posture procedure. This was considered quite reasonable considering the methods had never been previously used and the significant challenges of placing 9 accelerometers firmly enough to adequately collect data, yet not so firmly that the adhesive tape would dislodge from the patient during the torque generated during side-posture positioning and SMT.

The strict enrollment criteria just discussed were designed to allow for maximum cavitations in normal Z joints. Results in patients with moderate to severe Z joint degeneration (e.g.,

older, heavier patients) and patients with low back pain may differ; further research is needed to assess how these variables impact cavitation.

The modification of the SMT procedure to contact the infero-lateral sacrum, although necessary to avoid contact with accelerometers, made the SMT a longer lever procedure. This SMT modification may have decreased the force and the “accuracy” of the SMT, potentially reducing the total number of cavitations and producing more cavitations in the non-target area than if the posterior superior iliac spine was used as a contact. In spite of this, the SMT produced ample cavitations with over 70% of them originating from target area Z joints, allowing for adequate study of cavitations.

The results of this study cannot be generalized to the cervical and thoracic regions because of the unique morphology of the Z joints in these regions and because SMT procedures in the cervical and thoracic regions generally differs from the SMT used in this study.

Finally, this study did not assess the relationship between cavitation of identified Z joints and gapping of the same joints, or cavitation of identified Z joints and clinical outcomes (reduction in pain and functional impairment, etc.) and such work is needed to determine the clinical significance of cavitation.

Conclusions

The new accelerometry methods designed for this study were effective in assessing cavitations. These methods can be used in future clinical studies evaluating SMT. The distribution of Z joints that cavitated following lumbar SMT or side-posture positioning only was determined and has never been previously reported. Most cavitations (93.5%) occurred on the up-side (left side) of SMT and in the targeted segments (L3/L4, L4/L5, L5/S1 = 71.7%). As expected, subjects receiving SMT (96.7% of Group 1 subjects) cavitated more frequently, although cavitations were recorded from 30% of those receiving side-posture positioning only (Group 2 subjects). The finding of multiple cavitations from the same Z joints also has not been previously reported. Further research is needed to assess this phenomenon. Further research is also needed to determine differences in cavitation of the cervical, thoracic, and lumbar regions as well as differences in older subjects and subjects with low back pain.

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Figure 1.

Methods used in this study to accurately identify proper vertebral levels; a = high signal intensity MRI marker, which when taped to the subject (b) was used to verify palpated L4 spinous process (L4 spinous process was used as the major landmark for placement of all accelerometers); c = neutral supine MRI scan being performed; d = scout MRI showing correct placement of high signal marker at the spinous process of L4.

Figure 2.

Placement of accelerometers and spinal manipulation; a = illustration showing placement of 9 accelerometers; b = close-up of accelerometer (actual size $\sim 1.0 \text{ cm}^3$); c = subject with the 9 accelerometers placed for recording (white dots placed over each accelerometer); d = spinal manipulation performed while recording from accelerometers.

Figure 3.

Recordings from accelerometers; a = oscilloscope recording from accelerometers of a cavitation; b = the same recording shown in "a" with the timeline expanded to show the order in which the accelerometers recorded a vibration. Notice that the accelerometer located 3 cm to the left of L4/L5 fired first ("1" in 4b, this was the only accelerometer positioned to the left of the median plane). The next accelerometers to fire were those positioned over the L3 spinous process (SP, "2" in the figure) and L4 SP ("3" in the figure). These accelerometers fired almost simultaneously. Consequently, this recording indicated a cavitation of the left L3/L4 Z joint.

Figure 4.

Study Enrollment: Of the 99 telephone screens for this study, 74 were eligible to participate and attended the baseline visit, 49 were eligible following the baseline visit and MRI screening, and 40 were analyzed as complete sets of data (Group 1 = adjustment, or spinal manipulative therapy, n=30; Group 2 = side-posture positioning without spinal manipulation, n=10).

Figure 5.

Results of the recordings from 40 subjects. The illustrations of the posterior view of the spine in “a” and “b” show the individual Z joints and the numbers on the left and right of the illustration are the number of cavitations for each vertebral level (Note: Only 1 cavitation is recorded here in the cases of multiple cavitations from individual joints.); a = Group 1, side-posture spinal manipulation group; b = Group 2, control group (side-posture, but no spinal manipulation). The red brackets indicate the target area of the adjustments (L3/L4, L4/L5, and L5/S1). The results show that the left Z joints in the target area had significantly more cavitations than both right-sided joints and Z joints outside the target area. The results also show that Z joints of Group 1 subjects cavitated significantly more frequently than those of Group 2.

Model of One of the Effects of Spinal Manipulation Therapy (SMT)

Figure 6.

Flowchart showing a model of putative beneficial anatomical/biomechanical effects of spinal manipulation.

Table 1**Inclusion and Exclusion Criteria.¹**

Inclusion Criteria	Exclusion Criteria
<ul style="list-style-type: none"> • Eighteen to 30 years of age • 190 pounds or less for males and 150 pounds or less for females • No previous history of low back pain lasting for more than two weeks, or no more than three episodes of back pain of brief duration (one to two weeks) in any given year 	<ul style="list-style-type: none"> • Under 18 or over 30 years of age • Weight over 190 pounds for males and 150 pounds for females • History of an episode of LBP lasting for more than two weeks, or more than three episodes of back pain of brief duration (one to two weeks) in any given year • Presence of disc degeneration, significant osteoarthritis, lumbar scoliosis of greater than 5 degrees (Cobb's angle), or other significant pathology seen on previously taken x-rays or on x-rays requested for this study • Positive findings on the standard orthopedic or neurological tests of the study physical examination • Pregnancy • Presently breast-feeding an infant • Inability of clinician to obtain cavitation during lumbar side-posture adjustment given at the conclusion of the examination • Intolerance to MRI procedures of the study • Significant pathology discovered on MRI scans contraindicating spinal manipulation (e.g., cancer or fracture).

¹The inclusion and exclusion criteria were similar to those previously used in a case series (5 subjects) designed to assess the feasibility of this study. The criteria were designed to enhance the likelihood of cavitations and high quality MRI scans. Explanations for each criterion are described in that report.²¹

Table 2

Distribution of 46 Cavitations.

Joint level	Number of Cavitations	
	LEFT (%)	RIGHT
L1/L2	6 (13.04%)	0 (0.00%)
L2/L3	5 (10.87%)	0 (0.00%)
L3/L4	19 (41.30%)	0 (0.00%)
L4/L5	8 (17.39%)	1 (2.17%)
L5/S1	4 (8.70%)	1 (2.17%)
SIJ	1 (2.17%)	1 (2.17%)