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Evaluating the Relationship among Cavitation, Z Joint Gapping, and Spinal Manipulation: An Exploratory Case Series

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Abstract

Purpose—This IRB-approved project determined the feasibility of conducting larger studies assessing the relationship between cavitation and zygapophysial (Z) joint gapping following spinal manipulative therapy (SMT).

Methods—Five healthy volunteers (average age 25.4 years) were screened and examined against inclusion and exclusion criteria. High signal MRI markers were fixed to T12, L3, and S1 spinous processes. Scout images were taken to verify the location of the markers. Axial images of the L4/L5 and L5/S1 levels were obtained in the neutral supine position. Following the first MRI, accelerometers were placed over the same spinous processes and recordings were made from them during side-posture positioning and SMT. The accelerometers were removed and each subject was scanned in side-posture. The greatest central A-P Z joint spaces (gap) were measured from the first and second MRI scans. Values obtained from the first scan were subtracted from those of the second, a positive result indicating an increase in gapping following SMT (positive gapping).

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difference). Gapping difference was compared between the up-side (SMT) joints vs. the down-side (non-SMT) joints and between up-side cavitation vs. up-side non-cavitation joints.

Results—Greater gapping was found in Z joints that received SMT (0.5 ± 0.6 mm) vs. non-SMT joints (-0.2 ± 0.6 mm), and vertebral segments that cavitated gapped more than those that did not cavitate (0.8 ± 0.7 mm vs. 0.4 ± 0.5 mm).

Conclusions—A future clinical study is quite feasible. Forty subjects (30 SMT and 10 Control) would be needed for appropriate power (0.90). Partial funding by NIH/NCCAM (#2R01AT000123).

Introduction

Figure 1 summarizes the theory upon which this study was designed. Gapping is the separation of the zygapophyseal (Z) joint articular facets that occurs during spinal manipulative therapy (SMT) and side-posture positioning.¹ Z joint gapping during SMT is considered by many to be beneficial because the separation of joint surfaces during gapping is thought to (1) break up connective tissue adhesions that develop in hypomobile Z joints²⁻⁴ (steps 1–5b Figure 1), and (2) stimulate afferent nerves that innervate the Z joint capsule and the small muscles of the spine⁵⁻⁷ resulting in reflex neurological^{5,8-16} (steps 3–5a Figure 1) and possibly immunological^{15,17,18} consequences. Figure 2 summarizes the theoretical relationship between Z joint gapping and cavitation. Cavitation (a.k.a., audible release, the joint sound made during a spinal manipulation) is thought to be an indication that the Z joint has moved into the end range of joint motion¹⁹⁻²² and that gas (probably carbon dioxide) has entered the joint.^{23,24} Therefore, a cavitation has been interpreted as an indication that the joint has "gapped."^{25,26} After a thorough review of the literature, Brodeur²⁴ proposed that cavitation was caused by the elastic recoil of the synovial capsule (Figure 2) away from the joint space during the gapping caused by SMT. He continued by stating the Z joint capsular recoil was the specific action that initiated the beneficial neurological reflex actions (decreased pain and muscle relaxation) mentioned above (steps 3–5a Figure 1). Brodeur's theory heightens the importance of cavitation, making cavitation essential to many of the putative therapeutic benefits of SMT. Consequently, studying cavitation in Z joints and the SIJ may be important in understanding the therapeutic value of gapping.

Gapping and cavitation of the Z joints following SMT (a.k.a., spinal adjusting) have both been separately demonstrated,^{1,27-31} and even though the 2 phenomena (cavitation and gapping) have been thought to be related to each other during SMT for at least a century,⁴ there has been no evidence to support this relationship. Therefore, it becomes important to specifically study the relationship between cavitation and Z joint gapping during SMT.

This study had a twofold purpose. The first purpose was to test methods used to study the relationship between cavitation and therapeutic L4/L5 and L5/S1 Z joint (facet joint) gapping. Novel methods of 1) using the output of accelerometers to assess Z joint cavitation²⁹ and 2) determining Z joint space widening (gapping) by means of direct measurements from MRI scans^{1,27,28} had been previously published. Both methods employed elaborate data collection procedures and had never been used in conjunction with one another. In addition to evaluating these methods in general, the following specific aspects of the methods were to be assessed: identification of specific spinous processes (SPs) for accurate placement of accelerometers by means of palpation verified with MRI; recording from accelerometers on an MRI gantry table without interference from the MRI magnet; recording of multiple cavitations from a single SMT; and the use of multiple clinicians to perform SMT on different study subjects and multiple radiologic technicians to take the MRI scans (because multiple clinicians and technicians might be needed for logistics of subject scheduling in a larger study).

The second purpose of the study was to collect preliminary data assessing the relationship between cavitation and gapping. If the methods of this project were found to be feasible and the preliminary data showed a positive relationship between cavitation and gapping then further studies with larger numbers of subjects could be designed and conducted. Such future work would help deepen the understanding of the mechanism of action of SMT. In addition, if the results of the larger study indicated that cavitation and gapping of the Z joints were related, then cavitation could possibly be used in research and practice as a simple marker for a quantified amount of gapping.

Our hypothesis was that Z joints that cavitated would gap more than those that did not cavitate. Notice that the purpose of this study was not to compare SMT to another type of therapy or to a control group to determine a more effective treatment. Other investigators have addressed and continue to address such questions.^{32–35} Rather, the purpose of this study was to develop a better understanding of the mechanism of action of chiropractic SMT.

Methods

Subjects, Screening, and Enrollment

This IRB approved project sought 5 healthy subjects from the NUHS student population. Healthy subjects were used in order to minimize confounding variables (e.g. Z joint and intervertebral disc degeneration). Following initial screening, potential subjects went through the informed consent procedure. Those consenting were examined against inclusion and exclusion criteria (Table 1) designed to include healthy subjects without a history of low back pain. Those remaining eligible after the examination were enrolled in the study and scheduled for an MRI appointment.

MRI Appointment and Accelerometry

Following standard MRI screening, the subjects were placed in the prone position on the MRI gantry table and 2 clinicians reached consensus on the location of the spinous processes of T12 and L3 and the sacral tubercle of S1. Three high signal MRI markers (1.5 mm diameter and 3 cm long laboratory tubing filled with mineral oil) were then fixed with adhesive tape over the same spinous processes (Figure 3A and 3B).

Two radiologists, trained in imaging the spine with MRI, used previously published MRI positioning and scanning protocols designed to image the Z joints to best advantage.^{1,27,28} One radiologist performed scans for the first 2 subjects, the second for the last 3 subjects. Coronal and sagittal scout images were obtained using an open MRI unit (Hitachi MRP 5000, 0.2-T MRI unit; Hitachi Medical Systems America, Inc., Twinsburg, OH). The sagittal scout views were used to identify the location of the high signal markers and both the sagittal and coronal views were used to ensure proper patient positioning. Axial (transverse plane) MRI images were then taken of the L4/L5 and L5/S1 levels (5 images for each level). These initial (first) MRI scans were done with the subject in the neutral supine position (Figure 3C). A radiologist immediately evaluated the scans for pathology and developmental anomalies that would contraindicate SMT or might preclude cavitation or gapping (e.g., a transitional segment or hypoplastic articular process). The precise locations of the high signal markers were also noted from the sagittal scout images (which included the lower thoracic through sacral regions, Figure 3D) to allow for accurate placement of the accelerometers.

After the radiologist read the first scan for pathology, the subject was placed prone, while remaining on the MRI gantry table, and the high signal markers were removed. The high signal markers left a slight indentation on the subjects' back and this was used in

conjunction with the MRI scans to place the accelerometers either in the precise location where the high signal markers had been (if the markers had been correctly placed on the SPs of T12 and L3 and the S1 sacral tubercle), or based on the MRI scans, an adjustment was made superiorly or inferiorly 1 spinous process to place the accelerometers over the appropriate (T12, L3, and the S1) spinous process/sacral tubercle (Figure 4A-C). Table 2 gives the specifications of the accelerometer data acquisition system used in this study. The accelerometers were held in place with adhesive tape. Subjects were then positioned as if being set up for a side-posture SMT and the distances between the S1 to L3 and L3 to T12 accelerometers were carefully measured. The SMT clinician then stated when he was ready to perform the SMT, at which time recording from the accelerometers began and continued for 4 seconds (well beyond the completion of the SMT) while the clinician delivered the SMT (Figure 4D). Because SMT is not as specific as once assumed (i.e., if a single specific Z joint is targeted it often is not the joint that cavitates during SMT),²⁹ the proposed study used a general SMT directed at the lower lumbar (L4/L5 and L5/S1) segmental levels.³⁶ Notice in Table 2, 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 3.15×10^{-6} seconds. A cavitation wave travels through the human body at approximately 1400 m/sec. Therefore, the cavitation wave moved about 0.4 cm each time a sample is taken. As such the system allows us to determine from where the cavitation emanated to within 0.4 cm of its origin. Vertebrae in the lumbar spine are separated by a distance of 3 to 4.5 cm depending on the height of the individual. For example the L4/L5 Z joints would be 3 to 4.5 cm superior to the L5/S1 Z joints. Therefore, the sample rate provided more than ample discrimination to determine from which segmental level of Z joints (e.g., left or right L3/L4) each cavitation originated. Frequency analysis of the cavitation signal yielded a maximum frequency of 21,500 Hz. Hence the sample rate was well above the minimum required to prevent frequency aliasing. In addition, the sample rate (320,000 Hz) of more than 10 times the maximum frequency (21,500 Hz) ensured the sampled signal accurately reflected the cavitation waveform in the time domain.

Following the SMT, the research assistant asked the clinician if he heard, or felt through his contact hand, a cavitation during the SMT. This information was taken because the cavitation data recorded from the accelerometers and stored on the study computer took up to 1 hour to review and interpret. Consequently, the clinician's opinion as to whether or not a successful cavitation was achieved was used to determine if the subject should receive SMT on the opposite side in an attempt to obtain at least 1 cavitation from each subject. Consequently, all subjects received SMT on the left side (left side up) in this case series (Figure 4D) and 2 subjects (Subjects 3 and 5) also received SMT on the right side. In the last 3 subjects, recordings were also made during the set up (final positioning) procedure; this was done after several cavitations were heard during the final positioning with the left side up on the third subject.

To test the feasibility of recording from SMTs of different clinicians, 2 clinicians each performed the positioning and SMT of 2 of the 5 subjects (total of 4 subjects) and a third clinician performed the procedures on 1 subject. Subjects received SMT from only 1 clinician.

Following the SMT, the accelerometers were removed and the subject was immediately MRI scanned in the side-posture position (Figure 4E, the up-side was the side that received the final SMT) using protocols designed specifically for imaging the Z joints in this position.^{1,27,28} Previous studies assessed additional groups that were placed back in the neutral position for the second scan either following SMT or no SMT.^{1,27} Those results indicated that no additional useful information would be gained by adding such groups to

this study. Each subject was released from the study after the second MRI scan was completed.

The accelerometers used in this study had been chosen in a previous study because the frequency of the Z joint cavitations coincided with the resonant frequency of the accelerometers.²⁹ Each cavitation created a very distinct signal on the computer oscilloscope, allowing for the identification of the precise time sequence in which the accelerometers received the signal from the cavitation (Figure 5A and 5B). Using an algorithm written for previous studies,²⁹ the measured distances between the accelerometers, and the known velocity of vibrations originating from cavitations (1,400 m/sec),²⁹ the computer calculated the distance of each cavitation from each of the 3 accelerometers and from that information determined between which 2 accelerometers each cavitation originated. By knowing the accelerometers were located on the spinous processes of T12, L3, and S1 (sacral tubercle), the distances between the accelerometers, and the distance of the cavitations from each accelerometer; the segmental level from which the cavitation originated was determined using the scaled sagittal scout MRI film that showed the location of the spinous processes of T12-S1 (similar to the mid-sagittal scout view shown in Figure 3D only taken in the side-posture position).

MRI Morphometry

Specific protocols^{1,27,28} were employed by a radiologist, blinded to the segments that cavitated, to identify the specific MRI images used for morphometric analysis of the left and right L4/L5 and L5/S1 Z joint spaces (gaps). The greatest A-P distance between the articular processes at the center of the Z joints were then measured from the selected MR images (Figures 6A and 6B). This was done for the first and second scans of all subjects. The measurements were made using a GTCO Calcomp Drawing Board III digitizer (Source Graphics, Anaheim, California) with an accuracy of 0.07 mm. Measurements made using these methods were found to be reliable in previous studies.^{1,27,28} The value for each joint obtained from the first scan (rounded to the nearest 0.1 mm) was subtracted from that of the second to yield the gapping difference. A positive result in gapping difference indicated an increase in gapping following the SMT.

Analysis of Data – Descriptive Statistics

Because this exploratory study was not powered to use inferential statistics or to test hypotheses, descriptive statistics (means, standard deviations, standard errors) were used. More specifically mean gapping differences (MGD) of the up-side (SMT) joints (i.e., up-side during the last SMT and the second MRI scan) were compared with the MGD of the down-side joints, and the MGD of the up-side cavitation joints were compared with the MGD of the up-side non-cavitation joints. A higher MGD for up-side vs. down-side and up-side cavitation vs. upside non-cavitation would indicate that the up-side was the side receiving the greatest force from the SMT and that cavitation was related to increased gapping.

Results

Recruitment and Enrollment of Subjects and General Assessment of Methods

Five healthy subjects were recruited (4 female and 1 male; age range = 25–27 years, average age = 25.4 years; weight range 118–165 pounds, average weight = 133.8 pounds). All of the potential subjects consented, remained eligible after the examination, and were scheduled for the MRI appointment. No subjects were excluded following the first MRI scan.

The accelerometer and MRI methods were successfully implemented. The high signal markers were useful in positively identifying the appropriate spinous processes for accelerometer placement (Figure 3D). The high signal markers were positioned correctly in 12 of the 15 placements. In 3 instances (2 on 1 subject, Figure 3D) the markers were placed either above or below that of the corresponding high signal marker, indicating the inappropriate spinous process had been originally chosen. The appropriate adjustment was then made when placing the accelerometers. The MRI magnet did not interfere with the accelerometers even though the accelerometers were placed while the subjects remained on the MRI gantry table. As found previously,²⁹ the cavitations had a very distinct acoustic signature (Figure 5) and were readily differentiated from vibrations associated with the SMT in general and from the clinician accidentally hitting the accelerometer during a manipulative procedure. Also consistent with previous findings, the accelerometry methods could successfully record multiple cavitations (from different vertebral levels) in the same subject²⁹ (Table 3, subjects 1 and 3–5). Finally, gapping was able to be measured from the MRI scans of all the L4/L5 and L5/S1 Z joints, allowing for the gapping differences to be calculated for all the joints as well.

Summary of Cavitations and the Relationship of Cavitation to Gapping

Table 3 shows the distance of each cavitation from the accelerometer nearest to the cavitation, the distance from each cavitation to the T12 accelerometer, and the vertebral level for each cavitation. The clinician heard cavitations during the left side up SMT of the first subject. The 2 cavitations in Subject 1 were both later identified to be from the L1/L2 level (most likely from both the left and right L1/L2 Z joints, see Discussion). A single cavitation was heard during the left side up SMT of Subject 2, and a cavitation of small amplitude was recorded from the L5/S1 level by the accelerometers. The exploratory case series design of this study allowed for additional recordings (for Subjects 3 and 5) and longer recordings (for Subjects 3–5) to be performed on the last 3 subjects. Because the clinician heard cavitations during the final left side up positioning of the third subject and no cavitations were heard during the left side up SMT, recording during positioning began with the right side up positioning of the same third subject. Recording with the right side up of this subject began before final positioning and 2 cavitations were heard, and later verified as being recorded from L4/L5 and L5/S1 levels, during this (second) set-up procedure. An SMT was then given with the right side up with no additional cavitations heard or recorded. Because of these results, recording was conducted during positioning for the following 2 subjects in this case series (last 2 subjects, Subjects 4 and 5). Subject 4 did not cavitate during positioning with the left side up, but did cavitate twice during the left side up SMT (later determined to be L1/L2 and L2/L3). Consequently, this subject was not positioned on the right side. No cavitations were recorded on Subject 5 during left side up positioning or SMT. This subject was then positioned on the opposite side (right side up), and 1 cavitation (later identified as originating from L4/L5) was recorded during the right side up positioning and another (later determined to be from the sacroiliac joint [SIJ]) during the right side up SMT. The positioning and SMT cavitations could be differentiated by the time they appeared on the time-stamped oscilloscope. Overall, cavitations were recorded during positioning for 2 of the last 3 subjects (Subject 3 and Subject 5), and 2 subjects were positioned and received SMT with the right side up (also Subjects 3 and 5).

Figures 7 and 8 and Table 4 summarize the results of the gapping and cavitation data. A cavitation was recorded from 4 up-side L4/L5 and L5/S1 segmental levels (additional cavitations were recorded from L1/L2, L2/L3, and the SIJ). No cavitation was recorded from the 6 other up-side L4/L5 or L5/S1 segments. Greater gapping (i.e., a greater “gapping difference”) was found in the Z joints of the up-side (0.5 ± 0.6 mm) (left side for Subjects 1, 2, and 4, and right side for Subjects 3 and 5 where the most recent SMT was given) than

those of the down-side (-0.2 ± 0.6 mm). In addition, up-side Z joints with recorded cavitations showed greater gapping (i.e. a greater “gapping difference”) than those that did not have recorded cavitations [$0.8 (\pm 0.7)$ mm vs. $0.4 (\pm 0.5)$ mm].

Discussion

The methods used in this study were found to be feasible for use in future research. The results showed that the up-side joints (up-side during SMT, the side on which the clinician’s contact hand was placed) gapped more than the down-side joints, and joints that cavitated gapped more than those that did not. Several issues could benefit from further discussion; these include: the clinical relevance and reasons for pursuing this area of research, feasibility of the methods for future research, discussion of the results, the limitations of the research, and implications for future investigation. These topics will be covered in the following sections.

Clinical Relevance and Reasons for Pursuing this Area of Research

Studies assessing the clinical relevance of cavitation have shown mixed results. Theodorczyk-Injeyan et al. found that release of the proinflammatory cytokines tumor necrosis factor (TNF) alpha and interleukin (IL) 1beta, were decreased (suppressed) in subjects who cavitated during SMT compared to those who did not cavitate.¹⁸ However, the same research group later found no significant difference in the immunoregulatory cytokine interleukin 2 (IL-2) between cavitation and non-cavitation SMT subjects, although both groups showed significantly elevated IL-2 levels compared to controls and the cavitation group trended toward retaining the higher blood levels of IL-2 for a longer period of time.³⁷ Flynn et al.^{38,39} concluded that the audible release (cavitation) is not related to positive clinical outcomes (increase range of motion, decreased disability, and decreased pain). Their studies used a manipulative technique designed to be specific to the SIJs. The SIJs are atypical joints, usually categorized as an atypical synovial joint with “C” shaped articular surfaces and a complex series of interlocking “tongue and groove” surfaces to limit motion.⁴⁰ The Z joints are dramatically different from the SIJs, being synovial (diarthrodial) planar joints.⁴¹ As a result, extrapolation to the lumbar Z joints of the findings from research using techniques designed to affect the SIJs is somewhat problematic. In summary, the literature indicates a need for more detailed studies exploring the mechanism(s) and consequences of cavitation during SMT, specifically SMT directed at the Z joints, rather than the SIJ. Such studies would hopefully shed light on the Z joint changes that occur during a cavitation and how these changes relate to clinical practice. In fact, these were the kinds of future studies recommended by Flynn et al.^{38,39} and Beffa and Mathews.³⁰ The study reported here was designed to begin the process of addressing these current gaps of knowledge related to cavitation and SMT.

Feasibility of the Methods for Future Research

A future clinical study assessing the relationship between cavitation and gapping was determined to be quite feasible because all of the methods were successfully implemented in this exploratory study. Combining consensus palpation of 2 clinicians and MRI verification accurately identified the T12, L3, and S1 spinous processes. The clinicians and radiologists were all able to follow the protocols and carry out their responsibilities with no significant problems; thus indicating that more than 1 clinician and/or radiologist could be a part of future investigations. This is important for accommodating the scheduling of greater numbers of subjects in larger clinical trials.

One concern before the study began was whether or not the accelerometers would produce a non-distorted signal, free of interference from the MRI magnet. In fact, the signals from the

accelerometers were not affected in any way by the low field strength MRI magnet used in this study, even though the subjects were on the MRI gantry table with the accelerometers in place and were less than 6 feet from the magnet. The lack of interference to the accelerometers and the large opening of the MRI magnet that allowed for side-posture scanning were advantages of the particular MRI unit used for this study (Hitachi MRP 5000, 0.2-T MRI unit).

Discussion of the Results

Although this exploratory study did not have a sufficient number of subjects to draw definitive conclusions, the data clearly showed a trend for increased gapping of Z joints receiving a side-posture SMT, and also a trend for an increase in gapping of joints that cavitated. There are several items worth mentioning. First, the up-side joints gapped more than the down-side joints even including those subjects (Subjects 3 and 5) in which both sides received an SMT (i.e., Subjects 3 and 5). Recall that Subjects 3 and 5 were rotated and received SMT with the right side up when no cavitations were recorded during SMT with the left side up (also recall that “premature cavitations” occurred during positioning in Subject 3 when the left side was up). Previous work has shown that the side-posture position alone gaps the up-side Z joints and holds them in an open position; however, the force of SMT results in additional gapping beyond that caused by side-posture positioning alone.¹ Alternately, the downside joints are “close packed” during the loading received during side-posture positioning. Consequently, the up-side Z joints during final SMT and MRI were expected to gap more than the down-side joints even when both sides received SMT. Worth emphasizing is that the up-side Z joints that were found to cavitate gapped more than the other up-side Z joints.

There were not enough data to assess the difference in gapping between cavitations that occurred during the preliminary positioning of subjects and the cavitations that occurred during SMT. This would be an interesting area to assess in future research.

Finally, 2 cavitations were recorded from the L1/L2 level in Subject 1. This would indicate that either both the left and right L1/L2 Z joints cavitated or that 1 of these joints cavitated more than once, the latter case has never previously been noted in the literature (see Limitations and Implications for Future Investigation, below).

Limitations

There were several limitations to this exploratory study. Due to budgetary limits, the side of cavitation was not determined because additional accelerometers and the related amplifying and processing equipment would be needed to accomplish this. Because the side of cavitation was not determined, some of the cavitations recorded could have come from the down-side, obscuring the results (for example, and as previously discussed, this was a possibility with the 2 L1/L2 cavitations in Subject 1). Future studies should use additional accelerometers to determine the side of cavitation. Also, only L4/L5 and L5/S1 levels were MRI scanned in this study, limiting the number of joints that could be assessed. Future studies should include at least 1 more segmental level (L3/L4) in order to increase the number of joints that could be assessed with MRI. The increased number of joints would increase the power of the study and the added vertebral level would also help increase the generalizability of the results to a larger region of the lumbar spine. However, increasing the number of joints included in the MRI scan would increase the time the subject would spend on their side in the MRI unit. Consequently, increasing the number of Z joints scanned in future studies needs to be balanced with subject comfort.

Another limitation was the methods differed slightly for the last 3 subjects than for the first 2. Two of the last 3 subjects (Subjects 3 and 5) were positioned and received SMT on both sides and in all 3 of these subjects recording from the accelerometers began during the side-posture positioning that immediately preceded the SMT. Even though positioning and administering SMT on both the left and right sides of subjects (as with Subjects 3 and 5) would not be optimal in future research, such positioning in this study allowed for testing the methods (including the recording methods) more thoroughly with the limited number of subjects used in this feasibility study. In addition, these methods allowed us to determine that cavitations could be recorded during side-posture positioning alone. Future studies should record during the preliminary side-posture positioning and include a sufficient number of subjects so that all subjects would only be positioned and receive SMT on 1 side (e.g., all subjects with the left side up).

Even with these limitations, the results of this case series were quite promising. In addition to the data supporting a continuation of the research (i.e., the Z joints that cavitated gapped more than those that did not), methods used to measure cavitation and gapping with multiple technologies and many specially trained investigators were successfully implemented.

Implications for Future Investigation

This study was designed to begin the process of assessing the relationships between cavitation and gapping by evaluating methods that could be used to study these 2 variables in a larger project. To our knowledge there have been no studies that have simultaneously assessed the side and specific segmental level of Z joint cavitation, and none relating such variables to Z joint gapping. Reggars and Pollard determined the side of audible release in the cervical region, but did not identify the segmental level of gapping, because they used only 2 microphones, 1 placed on each side of the neck immediately anterior to the transverse process of C2.³¹ Microphones are less accurate than accelerometers for identifying the location of the source of a sound, and with only 2 microphones they were not able to estimate the segmental (vertebral) level of cavitation.

Based on the results of this project, a future study is planned using healthy subjects. A power analysis (MedCalc Software, Version 9.6.4, Mariakerke, Belgium) using effect size (0.4 mm) and variability (0.7 and 0.5 mm) estimates based on this study determined the recommended number of subjects in the proposed study ($\alpha = 0.05$ and 0.90 power). Forty (40) total subjects would be needed in 2 groups; 30 in an SMT group and 10 in a side-posture only control group.

Conclusions

This study evaluated accelerometry and MRI as novel assessment methods to simultaneously study Z joint cavitation (the joint sound related to SMT) and gapping (separation of the articular surfaces during SMT), 2 phenomena that are putatively related to one another. The methods were successfully implemented and data was collected on 5 subjects. The results indicated that during SMT, up-side lumbar Z joints (i.e., the joints receiving the direct force of SMT) gapped more than the down-side joints. In addition, the up-side Z joints that cavitated gapped more than those that did not cavitate. Consequently, cavitation and gapping appeared to be directly related (i.e., joints that cavitated tended to gap more than those that did not). A larger study is feasible and warranted.

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- Cavitation and zygapophysial (Z) joint gapping during spinal manipulative therapy (SMT) are two phenomena that have been studied independently but never together even though they are putatively related to one another.
- Current technologies in accelerometry and MRI morphometry allow for the simultaneous study of cavitation and Z joint gapping, and this exploratory case series of 5 subjects assessed the feasibility of doing so.
- Z joints receiving the direct force of lumbar SMT in a side-posture adjustment (the up-side) were found to gap more than the joints that did not receive the direct force (the downside) and the up-side Z joints that cavitated gapped more than those that did not cavitate.
- A larger study using the proposed refinements to the methods used in this report is feasible and warranted.

This study evaluated assessment methods and collected preliminary data for the simultaneous study of Z joint cavitation and gapping. The methods were successfully implemented and the preliminary data indicated the two variables appeared to be directly related (i.e., joints that cavitated tended to gap more than those that did not). Consequently a larger study is feasible and warranted.

Model of Beneficial Effects of Spinal Manipulation

Figure 1.

Flowchart showing a model of putative beneficial anatomical/biomechanical and neurological effects of spinal manipulation. Other putative effects (e.g., immunological effects) are not included in this flowchart.

Figure 2.

Theoretical mechanism of cavitation (joint sound) production. A = Posterior view of zygapophysial (Z) joints (right Z joint in box). B = Parasagittal section of Z joint showing Z joint synovial folds. C = Z joint adhesions developing in hypomobile joint. D = Therapeutic gapping (separation) of Z joint articulating facets breaking up adhesions while a cavitation (pop) is created.

Figure 3.

Taping of MRI high signal markers and the 1st (neutral position) MRI scan. A: Close-up of an MRI high signal marker fixed to the skin tape. B: A high signal marker being taped across the L3 SP. The markers were taped in a horizontal plane across the spinous processes (SPs) of T12, L3, and S1. C: MRI scanning in the neutral position with the high signal markers in place (markers not seen). D: Sagittal scout view MRI showing placement of 2 of the 3 high signal markers. The markers (white arrows) are the distinct, but small, high signal (white) structures visible to the right of (posterior to) the subcutaneous adipose tissue, which has a very high signal along the right side of the image. The intended placement of the high signal markers was directly posterior to the spinous processes (SPs) of T12, L3, and S1. The

lower black arrow indicates the SP of L3 and the black arrow at the top of the figure indicates the SP of T12. Consequently, a slight adjustment was made when placing the accelerometer over the SP of L3 (i.e., the accelerometer was placed 1 cm superior to the skin indentation made by the high signal marker). The most inferior (S1) high signal marker was visible on the adjacent image (5 cm lateral) to the image shown in this figure.

Figure 4.

Location and taping of accelerometers, spinal manipulation while recording from accelerometers, and 2nd (side-posture position) MRI scan. Once the correct location of the SPs were verified from the MRI scans showing the high signal markers, accelerometers were taped over the SPs of T12, L3, and S1. A: Illustration showing placement of 3 accelerometers. B: Taping the 3 accelerometers on the SPs. C: Close-up of an accelerometer (approximately 1 cm³). D: Spinal manipulation given while recording from the 3 accelerometers. E: Second MRI scan, this time in the side-posture position to maximize Z joint gapping following SMT (accelerometers removed following SMT).

Figure 5.

Examples of recordings from the accelerometers. A: Recording showing a cavitation. B: The time scale of the cavitation is expanded to show when each accelerometer first recorded a vibration. This information was used in an algorithm with previously measured distances between the accelerometers to determine the location of the cavitation with respect to the 3 accelerometers. This distance information was then compared with distances between the SPs and Z joints measured from the MRI scans to determine the Z joint(s) that cavitated (cross reference with Table 3). This cavitation occurred at the L4/L5 vertebral level.

Figure 6.

The central anterior to posterior (A-P) distance between the superior and inferior articular processes of the Z joints. A: Cartoon drawing showing A-P distance measurement. B: A-P measurement labeled on an MRI scan. This distance was measured for the left and right L4/L5 and L5/S1 Z joints from each subject's first and second MRI scans.

Figure 7.

Gapping Differences of SMT (up-side) vs. non-SMT (down-side) Z joints. The Gapping Difference for each Z joint was calculated as: (A-P measurement from 2nd MRI) – (A-P measurement from 1st MRI). A positive value indicated an increase in gapping following SMT. The SMT (up-side) joints showed more gapping than the non-SMT (down-side) joints. Notice the scale on the Y-axis includes negative values to accommodate the negative gapping difference of the down-side joints.

Figure 8.

Gapping Differences of SMT Z joints (i.e., up-side joints during SMT) that cavitated vs. those that did not cavitate. The SMT (up-side) joints that cavitated showed more gapping than the SMT joints that did not cavitate.

Table 1**Inclusion and Exclusion Criteria**

Inclusion Criteria	Exclusion Criteria
<ul style="list-style-type: none"> - Eighteen to 30 years of age (young age to decrease the likelihood of osseous and ligamentous degeneration of the lumbar region of the spine) - 185 pounds or less for males and 145 pounds or less for females (to ensure maximum image quality) - No previous history of LBP lasting for more than 2 weeks, or no more than 3 episodes of back pain of brief duration (1 to 2 weeks) in any given year (to recruit healthy subjects with no history, or a minimal history, of LBP) 	<ul style="list-style-type: none"> - Under 18 or over 30 years of age - Weight over 185 pounds for males and 145 pounds for females (subject will be weighed at exam) - History of an episode of LBP lasting for more than 2 weeks, or more than 3 episodes of back pain of brief duration (1 to 2 weeks) in any given year - Presence of disc degeneration, significant osteoarthritis, 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 (see below for reasons for x-ray, this study was attempting to assess subjects with healthy spines, also scoliosis decreases ability to adequately image the Z joints for measurement). - Positive findings on the standard orthopedic or neurological tests of the study physical examination form (to assess healthy individuals in the study, indications of somatic pathology or neurological deficit were exclusionary criteria) - Pregnancy (due to unknown risk and potential to require x-rays during the physical examination) - Presently breast-feeding an infant (unknown risk of MRI, also potential of need for x-ray during examination) - Inability of clinician to obtain cavitation [articular release(s)] during lumbar side-posture SMT given at the conclusion of the examination (the study assessed the relationship between cavitation and gapping, consequently ability to obtain a cavitation was important) - Intolerance to MRI procedures of the study (including claustrophobia and inability to lie on one's side for 15 minutes). - Significant pathology discovered on MRI scans contraindicating spinal manipulation. This criterion was evaluated during the MRI visit, immediately after the first MRI scan.

Table 2

Specifications of Accelerometry Data Acquisition System.

Equipment/Software	Specifications	Purpose/Comments
Accelerometers (3)	DataTron 4507 accelerometer Bruel & Kjaer, Naerum, Denmark Resonance Frequency: 19 kHz Sampling Rate: 320,000 Hz Samples to Read: 70,000 Sensing Element: Piezoelectric, Type PZ23 Outer Case: Titanium ASTM Grade 2	Resonated at natural frequency of cavitations. Three accelerometers allowed (through use of an algorithm) for localization of cavitations to specific Z joint segmental level (example, L3/L4 Z joint)
Amplifiers	Nexus Conditioning Amplifier, Model 2693 Bruel & Kjaer, Naerum, Denmark	Amplify signal from accelerometers. The amplifier was able to accommodate up to 4 accelerometers.
Data Processing Unit	PXIe 6356 National Instruments, Austin, Texas	Processing of signals from amplifier to PC laptop computer
Lab View Software	National Instruments, Austin, Texas 32 bit processing	Real time oscilloscope, simultaneous plotting and recording from 3 accelerometers. Allowed almost infinite variety of options (through additional programming) to plot and analyze accelerometry data.

Table 3

Identification of Cavitations from Accelerometry Data.

Subject	Recording	Up-Side	*Cavitation (Cav) #	Distance to Accelerometer Closest to Cav	Cav to 112 Accelerometer	Cav Location
1	SMT	Left	1st	4.0 cm sup to M	4.0 cm	L1/L2
	SMT	Left	2nd	3.1 cm sup to M	4.9 cm	L1/L2
2	SMT	Left	1st	1.3 cm sup to I	17.2 cm	L5/S1
3	SMT	Left	None			
	Positioning	Right	1st	3.6 cm sup to I	15.4 cm	L4/L5
	Positioning	Right	2nd	2.4 cm sup to I	16.6 cm	L5/S1
	SMT	Right	None			
4	Positioning	Left	None			
	SMT	Left	1st	.3 cm sup to M	8.7 cm	L2/L3
	SMT	Left	2nd	4.5 cm sup to M	4.5 cm	L1/L2
5	Positioning	Left	None			
	SMT	Left	None			
	Positioning	Right	1st	4.8 cm sup to I	15.7 cm	L4/L5
	SMT	Right	1st	0.2 cm sup to I	20.3 cm	SIJ

* In several instances multiple cavitations occurred during the same recording.

Table 4

Z Joint Gapping and Cavitation Data.

Subject # and Z Joint (Jt) Levels	Neutral		Side-posture		Gapping Difference (GD)		Cavitation Up-Side	Notes on Cavitation (Cav): Up-Side Left (L) or Right (R), Vertebral Level
	Upside L/R	Downside L/R	Upside L/R	Downside L/R	Upside	Downside		
Subject 1 L4/L5 L5/S1	L	R	L	R				2 Cavs from L1/L2 with SMT, L Side-up
	3.4	4.2	3.8	3.1	0.4	-1.1	N	
	3.3	3.4	3.3	3.3	0	-0.1	N	
Subject 2 L4/L5 L5/S1	L	R	L	R				L5/S1 with SMT – very low amplitude, L side-up
	3.8	4.5	4.3	3.8	0.5	-0.7	N	
	5.1	3.9	5.5	4	0.4	0.1	Y	
Subject 3 L4/L5 L5/S1	R	L	R	L				Several Cavs heard during L side-up positioning before recording began L4/L5 and L5/S1 during positioning with R side-up, none during SMT
	4.4	3.3	6.3	3.8	1.9	0.5	Y	
	4.3	3.5	4.7	2.3	0.4	-1.2	Y	
Subject 4 L4/L5 L5/S1	L	R	L	R				L1/L2 and L2/L3 with SMT, L side-up
	3.5	J.J	4.8	3.8	1.3	0.5	N	
	3.5	3.4	3.8	3.4	.0.3	0	N	
Subject 5 L4/L5 L5/S1	R	L	R	L				None L side-up L4/L5 during positioning, R side-up; Sacroiliac Joint during SMT, R side-up
	3.6	3.8	4.1	4.2	0.5	0.4	Y	
	3.7	4.1	3.4	3.8	-0.3	-0.3	N	
Average GD Upside and Downside (STD)					0.5 (±0.6)	-0.2 (±0.6)		
Average Cav Z Jts (STD)					0.8 (±0.7)			
Average NO Cav Z Jts					0.4 (±0.5)			

Subject # and Z Joint (Jt) Levels	Neutral		Side-posture		Gapping Difference (GD)		Cavitation Up-Side	Notes on Cavitation (Cav): Up- Side Left (L) or Right (R), Vertebral Level
	Upside L/R	Downside L/R	Upside L/R	Downside L/R	Upside	Downside		
(STD)							Yes (Y)/ No(N)	