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Quantification of Cavitation and Gapping of Lumbar Zygapophyseal Joints during Spinal Manipulative Therapy

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Abstract

Objectives—The purpose of this study was to use previously validated methods to quantify and relate 2 phenomena associated with chiropractic spinal manipulative therapy (SMT): 1) cavitation and 2) the simultaneous gapping (separation) of the lumbar zygapophyseal (Z) joint spaces.

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CONFLICTS OF INTEREST

No conflict of interest was reported by any of the authors.

Methods—This was a randomized, controlled, mechanistic clinical trial with blinding. Forty healthy subjects (18 to 30 years of age) without a history of low back pain participated. Seven accelerometers were affixed to the skin overlying the spinous processes of L1-L5 and the S1 and S2 sacral tubercles. Two additional accelerometers were positioned 3 cm left and right lateral to the L4/L5 inter-spinous space. Subjects were randomized into: Group 1—side-posture SMT (n=30) or Group 2—side-posture positioning (SPP, n=10). Cavitations were determined by accelerometer recordings during SMT and SPP (left-side=up-side for both groups); gapping (gapping difference) was determined by the difference between pre- and post-intervention MRI joint space measurements. Results of mean gapping differences were compared.

Results—Up-side SMT and SPP joints gapped more than down-side joints (0.69 vs. -0.17mm, $p<0.0001$). SMT up-side joints gapped more than SPP up-side joints (0.75 vs. 0.52mm, $p=0.03$). SMT up-side joints gapped more in males than females (1.01 vs. 0.49mm, $p<0.002$). Overall, joints that cavitated gapped more than those that did not (0.56vs. 0.22mm, $p=0.01$). No relationship was found between the occurrence of cavitation and gapping with up-side joints alone ($p=0.43$).

Conclusions—Z joints receiving chiropractic SMT gapped more than those receiving side-posture positioning alone, Z joints of males gapped more than those of females, and cavitation indicated that a joint had gapped, but not how much a joint had gapped.

Keywords

spinal manipulation; zygapophyseal joints; facet joints; cavitation; chiropractic

Introduction

Zygapophyseal (Z) joint gapping is hypothesized to be related to a therapeutic benefit of spinal manipulative therapy (SMT), and cavitation (audible joint sound during SMT) or the “audible release,” is hypothesized to be related to gapping. The audible release is thought to be the result of gas, most likely carbon dioxide, rapidly entering a Z joint and forming a gas bubble during the vacuum (cavitation) created as the articular facets rapidly separate during SMT.^{1,2} Other authors believe the audible release is caused by the collapse of the Z joint intra-articular gas bubble.³ Previously validated methods were used to measure gapping from MRI scans,^{4,5} and cavitation from recordings of accelerometers (sensors that respond to the vibrations produced by cavitating Z joints).^{2,6,7}

Z joint gapping has been associated with the break-up of intra-articular Z joint adhesions^{8–11} and other positive clinical outcomes.^{12,13} For at least a century, cavitation and Z joint gapping during SMT have been thought to be related;^{8,14} however, there has been little evidence to support this relationship.¹⁵ Recent research assessing SMT of the sacroiliac joint (SIJ) has indicated that cavitation is not necessarily correlated with positive therapeutic outcomes;^{16,17} however, those studies did not assess SMT targeting the lumbar region. Other investigators have found a positive relationship between SMT with cavitation and a reduction of proinflammatory cytokines,¹⁸ as well as mixed results with production of interleukin 2,¹⁹ and nociception.²⁰ None of these studies identified specific vertebral segment(s) that cavitated. Consequently, the studies were not able to relate cavitation with outcomes of cavitating Z joints (e.g., gapping).

Assessing cavitation and gapping of Z joints may provide information that enhances understanding of the mechanisms of action of SMT, which is important for improving the application and the outcomes of SMT.^{15,21–24} Although cavitation^{14,25,26} and gapping^{4,5} have been studied separately, only a small pilot study has evaluated both phenomena and their relationships simultaneously.²⁷

Therefore, further research is needed to assess the relationships between cavitation and gapping for commonly used SMT techniques specific to the lumbar region.^{14,15,18,19,24,25,27} This study was designed to determine the vertebral level and side (left or right) of cavitation during lumbar SMT and relate those findings to change in gapping of the Z joints. The purpose of this study was to quantify two phenomena related to spinal manipulative therapy (SMT) and their relationship to one another. The two phenomena were: 1) cavitation, and 2) the simultaneous change in gapping (separation) of the lumbar zygapophyseal (Z) joint spaces.

Materials and Methods

A thorough description of the subjects, SMT procedure, methods for verifying key landmarks for placement of accelerometers, recording and analyzing accelerometry data, and the location of cavitations from the 40 subjects is reported previously.^{6,28} This paper provides brief descriptions of the preceding methodology, but focuses on Z joint gapping, as measured by MRI in the same 40 subjects, and the relationship of gapping and cavitation, as measured by accelerometry. This project was approved by the Institutional Review Board (IRB) of the National University of Health Sciences (NUHS IRB # H-0906), which operates under Federal Guidelines CFR 45, Subsection 46.

Healthy subjects (18 to 30 years of age) without a history of low back pain were recruited from a health sciences university student population. Healthy subjects were used in order to minimize confounding variables in this initial dual assessment of Z joint gapping and cavitation. Following initial screening, consenting subjects were examined against rigorous inclusion and exclusion criteria.⁶ Those remaining eligible after the examination were enrolled and scheduled for an MRI appointment. The MRI appointment consisted of an MRI scan in the neutral supine position (Figure 1A), randomization into one of two groups, accelerometry procedures (Figure 1B), and a second MRI scan in the side-posture position (up-side=left side, Figure 1C).

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. Following standard MRI screening, the subject was placed in the prone position on the MRI gantry table and the L4 SP was identified via palpation. A high-signal MRI marker was then placed over the L4 SP. The location of the readily visible high signal marker was carefully noted on the mid-sagittal scout MRI scan and used for proper placement of nine accelerometers.⁶

First MRI Scan

Previously published MRI positioning and scanning protocols were used to image the Z joints to best advantage.^{4,5} Coronal and sagittal scout images were obtained (Hitachi MRP 5000, 0.2-T MRI open unit; Hitachi Medical Systems America, Inc., Twinsburg, OH). The sagittal scout views were used to identify the location of the high-signal marker and both the sagittal and coronal views were used to ensure proper patient positioning. Axial (transverse plane) MRI images in the neutral (supine) position (Figure 1A) were then taken of the L3-L4, L4-L5, and L5-S1 Z joints (5 images for each level). Three vertebral levels were the maximum number of lumbar segments that could be imaged without causing discomfort to the subject during the second (side-posture) MRI scan.

Following this first MRI, the subject was placed prone, while remaining on the MRI table, and the high-signal marker was removed. A radiologist immediately evaluated the scans for pathology that would contraindicate SMT, and for developmental anomalies (e.g.,

transitional segment, hypoplastic articular process, etc.) that might preclude cavitation or gapping. The slight indentation on the subject's back, left by the high-signal marker, was used in conjunction with the mid-sagittal scout MRI scans to positively identify the L4 SP. The nine accelerometers were then placed using the L4 SP as the primary landmark.

Placement of Nine Accelerometers

Tape with strong adhesive characteristics was used to affix seven 1-cm³ accelerometers (Figure 1B inset; DeltaTron 4507, Bruel & Kjaer, Naerum, Denmark) to the spinous processes of L1-L5 and the S1 and S2 sacral tubercles. In addition, two accelerometers were positioned 3 cm left and right lateral to the L4/L5 inter-spinous space. Figure 1B shows a subject with the nine accelerometers in place.

Randomization of Subjects

The subject was then randomized into one of two groups: Group 1 – side-posture SMT (n=30), and Group 2 –side-posture positioning only (n=10). Because cavitation during side-posture positioning alone was noted in a previous feasibility study,²⁷ a side-posture only group (no SMT, Group 2) was included in this study to control for the effects of the force of side-posture positioning. The number of subjects in Groups 1 and 2 of this study was determined from a power analysis using the effect sizes and data variability of the previously completed feasibility study.²⁷

SMT and Accelerometer Recordings

Once randomized, each subject was placed on his/her right side (i.e., left-side always the up-side, Figure 1B). The adjusting clinician stated when he was ready to perform the final side-posture positioning (both Groups 1 and 2) and SMT (Group 1 only), and then recording (320,000 Hz sampling rate) from the accelerometers began and continued for four seconds (well beyond completion of the SMT for Group 1) while the clinician delivered the SMT (Group 1) or held the subject in the final side-posture position (Group 2). Figure 1B shows the accelerometers in place (recording in progress) during the final SMT set-up. Because SMT is not as precise as once assumed,¹⁴ the proposed study used a general SMT (hypothenar ilium technique)²⁹ directed at the L3/L4-L5/S1 segmental levels. The SMT included two high-velocity, short-lever, low-amplitude thrusts delivered in rapid succession.⁶

The accelerometers were the same type used successfully in previous studies.^{14,27} They were chosen because the frequency of the Z joint cavitations coincided with the resonant (natural) frequency of the accelerometers.^{14,27} Each cavitation created a very distinct signal on the computer oscilloscope, allowing for the identification of the precise time sequence in which each of the nine accelerometers received the signal from the cavitation. The positive results of reliability studies [weighted kappa (Kw) = 0.94, SE ±0.06] and additional details of the accelerometry methods are described elsewhere.^{6,14}

Second MRI Scan

Following the SMT or side-posture positioning only procedure, the accelerometers were removed and the subject immediately received a second MRI scan in the side-posture position (Figure 1C, left side=up-side, same side as during accelerometer recordings) using positioning and imaging protocols designed specifically for scanning the Z joints in this position.^{4,5} Each subject was released from the study after the second MRI scan was completed.

Assessment of Cavitations

The accelerometer recordings were assessed for the presence of cavitations. Cavitations were identified from the oscilloscope recordings as dramatic shifts from the baseline of several accelerometers and by their unique waveform pattern (“non-continuous” or “damped” waveform pattern). The level of cavitation (e.g., right L3/L4 or left L4/L5) was identified by the order in which the recording line for each accelerometer deviated from the baseline.⁶

MRI Morphometry

Previously developed protocols^{4,5} were employed by a radiologist to identify the specific MRI images used for morphometric analysis of the left and right L3/L4, L4/L5, and L5/S1 Z joint spaces (gaps). The radiologist was blinded to all subject identification information (including gender), group randomization, and vertebral segments that cavitated. From the selected images, another investigator (same blinding) measured the greatest A-P distance (Figure 2A, inset) between the articular processes at the center of all the Z joints (first and second scans). Measurements were made with a digitizer (GTCO Calcomp Drawing Board III digitizer; Source Graphics, Anaheim, California). These methods were found to be reliable in previous studies (reproducibility=0.07 mm).^{4,5,30} The measured 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* for each joint. A positive gapping difference indicated an increase in gapping following the SMT or side-posture positioning.

Analysis of Data

Mean gapping differences were compared by one and two-tailed t-tests; one-sided for those parameters in which previous research predicted the direction of outcome, two-sided for those parameters in which there was no indication of the direction of change. The gapping differences were compared based on the following parameters: up-side vs. down-side (one-sided^{4,5}), Group 1 up-side vs. Group 2 up-side (one-sided^{4,5}), males vs. females (two-sided), joints that cavitated vs. those that did not cavitate (two-sided), and up-side joints that cavitated vs. up-side joints that did not cavitate (two-sided).

Results

Subjects

Fifty-nine (59) subjects completed the first MRI scan and accelerometry procedures. Ten subjects were excluded after the first MRI scan for pathology or complicating anomalies and nine were excluded after the accelerometry procedures because of incomplete data (i.e., one of nine accelerometers lost enough skin contact to preclude data acquisition from that accelerometer).⁶ The goal of 40 healthy subjects completing the study was attained (20 male and 20 female).⁶

Assessment of Gapping

The mean gapping difference of all up-side joints was significantly greater than that of down-side joints (n=240, 0.7 vs. -0.2 mm, $p<0.0001$, 95% CI=-1.0—0.7). This was also true for Group 1 and Group 2 separately: Group 1 (n=180, 0.8 vs. -0.1 mm, $p<0.0001$, 95% CI=-1.0—0.6), Group 2 (n=60, 0.5 vs. -0.4, $p<0.0001$, 95% CI=-1.2—0.7). Figure 2 shows MRI scans of a Group 1 subject before and after SMT.

SMT (Group 1) up-side joints (n=90) gapped more than side-posture position (Group 2) upside joints (n=30) (0.7 vs. 0.5, a difference of 0.2 mm, $p=0.03$, 95% CI=-0.5—0.0) (Figure

3). As expected, a decrease of joint space was found on the down-side, with Group 1 showing less of a decrease than Group 2 (-0.1 vs. -0.4 ; $p=0.01$, 95%CI= $0.1-0.6$).

Males receiving SMT (Group 1) gapped significantly more in their up-side joints than females ($n=90$, 1.0 vs. 0.5 mm, $p<0.002$, 95%CI= $-0.1-0.2$) (Figure 4), but were comparable in their down-side joints ($n=90$, -0.1 vs. -0.1 mm, $p=0.73$, 95%CI= $-.02-0.3$). This change did not hold for Group 2, side-posture positioning only, up-side joints ($n=30$, 0.5 vs. 0.5 mm, $p=0.81$, 95%CI= $-0.3-0.4$), and there was also no difference between male and female Group 2 down-side joints ($n=30$, -0.5 vs. -0.4 mm, $p=0.62$, 95%CI= $-0.4-0.6$).

Relationships between Cavitation and Gapping

Overall, joints that cavitated ($n=33$, 0.6 ± 0.6 mm) gapped more than those that did not cavitate ($n=207$, 0.2 ± 0.8 mm) ($p=0.004$, 95%CI= $0.1-0.6$) (Figure 5).

Analysis exclusive to the up-side joints found no relationship between the occurrence of a cavitation and gapping ($p=0.43$, 95%CI= $-0.2-0.4$). Joints that cavitated from SMT (Group 1, $n=28$) had approximately the same gapping difference as those that cavitated following side-posture positioning alone (0.61 ± 0.6 mm vs. 0.6 ± 0.7 mm), although the small number of joints cavitating following side-posture positioning alone (Group 2, $n=3$) precluded inferential analysis.

Discussion

Assessment of Gapping

The results indicate that the up-side during side-posture positioning and SMT gapped more than the down-side. The results also indicate that SMT gaps the Z joints more than side-posture positioning alone (Group 1>Group 2). These results support those of previous studies.^{4,5}

In addition, SMT gapped the up-side Z joints of males (the up-side is thought to receive the majority of force during lumbar SMT) significantly more than the up-side Z joints of females (Group 1 mean gapping differences; 1.0 ± 0.9 mm vs. 0.5 ± 0.6 mm = 0.5 mm more gapping in males, $p<0.002$). A portion of this interesting finding could possibly be due to a gender difference in size of the pre-SMT joint space. The joint space of the pre-SMT scans (first MRI scan of Group 1 subjects) of males was larger than that of females (Group 1 joint space size; 3.6 ± 0.5 mm vs. 3.4 ± 0.5 mm, = 0.2 mm larger joint space in males, $p=0.02$), which explains part, but not all of the difference. However, the Group 2 (side-posture positioning only group) mean gapping differences of up-side Z joints for male and female subjects were essentially the same (Group 2 mean gapping differences; 0.5 ± 0.6 mm vs. 0.5 ± 0.4 mm, $p=0.81$), even though the joint space of the pre-side-posture scans (first MRI scan of Group 2 subjects) was 0.3 mm greater in males (Group 2 joint space size; 3.6 ± 0.5 mm vs. 3.3 ± 0.4 mm, = 0.3 mm larger pre-side-posture joint space in males, $p=0.05$). These results indicate that even accounting for the pre-intervention joint space of males being greater than that of females, the Z joints of males receiving SMT gapped significantly more than those of females. Other authors have discussed the importance of assessing gender differences when evaluating Z joint motion and morphology.^{31,32} Further research is needed to better understand this phenomenon.

Relationships between Cavitation and Gapping

Overall, joints that cavitated gapped more than those that did not. However, this did not hold true when looking at the up-side joints alone. This is explained by the large difference between the mean gapping differences of the up-side versus the down-side joints (up-side

had a greater mean gapping difference than down-side); additionally, fewer down-side joints cavitated than up-side joints. Therefore, cavitation was an indication that an individual joint had gapped, but did not indicate how much a joint gapped. That is, joints that cavitated gapped more than those that did not, but not necessarily more than the neighboring up-side Z joints that did not cavitate.

These results provoke the question, “Why do some gapping joints cavitate and others do not?” Although more research is needed, several potential reasons seem plausible. The first reason is based on the direct relationship between cavitation and the rate of pressure change (i.e., a more rapid pressure change leads to an increased likelihood of cavitation).³³ Consequently, cavitation in Z joints may be related to tissue resistance to separation (gapping) of the superior and inferior articular processes and their facets. The greater the tissue resistance to gapping the more likely a joint may cavitate as it suddenly moves through tissue resistance, allowing the joint surfaces to separate more rapidly (and more rapidly changing the pressure within the Z joint) than the articular surfaces of surrounding joints. The more rapid joint surface separation would allow rapid entry of gas into the joint space, resulting in a cavitation. Increased resistance may be related to decreased Z joint synovial fluid, increased paraspinal muscle tension, and/or increased stiffness of connective tissues associated with the Z joints (i.e., ligaments and fascia surrounding the Z joints and small intra-articular Z joint adhesions that are found in almost all Z joints¹¹). As reported elsewhere,²⁸ six L3/L4 – L5/S1 Z joints cavitated more than once during the SMT (note: a multiple cavitating Z joint was counted as a single cavitating joint in this study). The pre-intervention joint spaces of the multiple cavitating joints were significantly narrower than joints that did not cavitate and those that cavitated only once ($Kw=9.09$, $p=0.002$).²⁸ This may lend support to the theory that the muscles closely associated with the multiple cavitating joints were under greater tension, or perhaps the connective tissues associated with these joints were stiffer (or intra-articular adhesions more abundant) than for Z joints that did not cavitate or cavitated only once. Consequently, once the tissue resistance was overcome, the joint surfaces separated more rapidly, and in the case of the multiple cavitating joints, separated in a stepwise fashion, resulting in more than one cavitation. Another potential explanation for cavitation is joint architecture (morphology). Differences in the size and shape of the articular surfaces of a Z joint may play a role in joint cavitation. This would seem to be consistent with the work of Bereznick et al. who found different refractory periods to the cavitation sounds (audible releases) in different individuals, and hypothesized that each Z joint may have a different audible release refractory period.² Future research, in healthy and low back pain populations, assessing the relationships among paraspinal tissue resistance, Z joint architecture (including changes with joint degeneration), age, cavitation, and gapping are needed to further determine the nature and clinical significance of Z joint gapping. The technologies of MRI, accelerometry, and acoustics make such future research possible.

Limitations

This study has several limitations. The research was performed on healthy young adult subjects and results on subjects in pain, with complicating conditions or anomalies, or different age groups may differ. In addition, the lumbar Z joints are distinctly different in architecture from the cervical and thoracic Z joints,³⁴ and further research in those regions is needed before the results of this study can be applied to the cervical and thoracic regions. One must also keep in mind that Z joint gapping is not a static function, but rather the joint space varies during the course of a manipulation and during motion. Further research is needed to assess the relationship of Z joint gapping on viscoelastic properties of the spine such as vertebral segmental stiffness.

Conclusions

This study used previously described methods to assess Z joint gapping and cavitation. Up-side joints during SMT and side-posture positioning gapped significantly more than down-side joints. Z joints receiving chiropractic SMT gapped more than those receiving side-posture positioning alone. In addition, the up-side Z joints of males gapped more than those of females. Overall, joints that cavitated gapped more than those that did not, but up-side joints that cavitated did not gap more than up-side joints that did not cavitate. Cavitation indicated that an individual joint had gapped, but did not indicate how much a joint had gapped.

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- Cavitation and gapping have been studied separately, but have not been sufficiently studied simultaneously. This study used novel, previously validated methods to assess Z joint gapping and cavitation.
- Z joints receiving chiropractic SMT gapped more than those receiving side-posture positioning alone.
- Z joints of males gapped more than those of females.
- Cavitation indicated that an individual joint had gapped, but did not indicate how much a joint had gapped.

Figure 1.

Subjects were first MRI scanned in the neutral supine position (A). Nine accelerometers were placed on each subject and the output from them was collected for a period of four seconds during spinal manipulative therapy (Group 1) or side-posture positioning (Group 2) (B; inset shows one of the 1.0 cm³ accelerometers). After recordings were completed, the accelerometers were removed and a second MRI scan was taken in the side-posture position (C).

Figure 2.

Pre- (A) and post-spinal manipulation (SMT) (B) horizontal plane (axial) MRI scans of a side-posture SMT subject (Group 1) demonstrating gapping of the left (L) L5/S1 zygapophyseal (Z) joint (left side = up-side during SMT). Notice that the central width (thickness) of the left post-SMT Z joint space (lateral edge of joint indicated by arrow in B) is wider than the left pre-SMT Z joint space (arrow in A). The central anterior to posterior (AP) distance between the superior and inferior articular processes of the Z joints was measured (2A, inset) for the left and right L3/L4, L4/L5, and L5/S1 Z joints from each subject's first and second MRI scans. Fig. 2B has been rotated counter clockwise 20 degrees for orientation similar to 2A.

Figure 3. Mean gapping difference of spinal manipulation (SMT) vs. no-SMT zygapophyseal (Z) joints. Z joints that received SMT (up-side, Group 1) had a greater gapping difference than controls (no-SMT, up-side Group 2).

Figure 4.

Mean gapping difference of female vs. male zygapophyseal (Z) joints. Z joints of males receiving spinal manipulation (SMT) (up-side, Group 1) gapped significantly more than the same joints of females.

Figure 5. Mean gapping difference of zygapophyseal (Z) joints that cavitated vs. those that did not cavitate. Z joints that cavitated gapped more than those that did not.