Comparable effect of simulated side bending and side gliding positions on the direction and magnitude of lumbar disc hydration shift: *in vivo* MRI mechanistic study

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Objectives: To investigate the direction and magnitude of mechanical influence to the lumbar disc in side bending and side gliding positions by considering shift of disc hydration.

Methods: Twenty asymptomatic subjects completed this study. Direction of the hydration shift (θ), magnitude of the shift, and segmental lateral flexion and rotation angles from L1/L2 to L5/S1 during left side bend and side glide in lying were measured by magnetic resonance imaging (MRI) and compared using paired *t*-tests.

Results: A significant difference ($P < 0.001$) was detected in the segmental lateral flexion angle at L1/L2 between the side bending position (mean [SD], 5.1° [2.2°] left lateral flexion) and the side gliding position (mean [SD], 2.1° [2.7°] left lateral flexion). However, there was neither significant difference ($P > 0.05$) in the lateral flexion angle at other segments nor rotation angles at each segment between the two lumbar positions. There was also no significant difference ($P > 0.05$) in the θ value and magnitude of the hydration shift between the two lumbar positions. The disc hydration generally shifted to the right in the left side bending and side gliding positions at all disc levels.

Discussion: This is the first study to investigate mechanical influence to each lumbar disc in the side gliding position using the shift of disc hydration on axial MRI. The comparability in the direction and magnitude of the hydration shift in the side bending and side gliding positions indicates that the maneuver of side gliding can produce comparable ipsilateral mechanical influence to each lumbar disc in comparison to side bending.

Introduction

Magnetic resonance imaging (MRI) is a useful tool to understand biomechanics within the intervertebral disc. Disc hydration profile is a quantitative measure to understand gross location of the healthy nucleus pulposus over the sagittal or coronal plane. The change of disc hydration profile from an original location (i.e. shift of disc hydration) indicates mechanical influence to the disc and has been used in previous studies.^{1–6} Disc hydration normally shifts to the contralateral side of the movement plane.^{2,4}

The directional response of the disc to various loading strategies has been used as the theoretical explanation for a directional preference in the

Mechanical Diagnosis and Therapy (MDT) system. In that system, side gliding (SG) is used as a repeated movement, or static loading, strategy for assessment, and treatment of patients who need lateral loading strategies. For example, left SG is a movement of the shoulders to the left relative to the pelvis where a line through the shoulders is maintained horizontally. From a biomechanical perspective, SG consists of less degrees of ipsilateral flexion at the upper levels (L1–L4) than side bending (SB).⁷ Thus, SB may produce greater lateral influence to the disc throughout the lumbar spine than SG although lumbar lateral alignment does not always correlate with the magnitude of the shift of disc hydration.^{2,6} Interestingly, SG is used in MDT rather than SB. It is not clear if there is any difference in the mechanical response of the disc between SB and SG.

A mechanistic study comparing the direction and magnitude of disc hydration shift on axial MRI in

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response to SB and SG positions may help to identify differences in the mechanical influence to the disc between these two motions. Such a biomechanical understanding of SG will enable us to consider the most effective maneuver for lateral mechanical loading strategies to the disc. Hence, the purpose of this study was to investigate the direction and magnitude of mechanical influence to each lumbar disc in response to SB and SG by analyzing shift of disc hydration on axial MRI.

Methods

MRI equipment

A 0.2-T horizontally open MRI unit (AIRISmate, HITACHI Inc., Sapporo, Japan) was used in this study and five MRI conditions were captured (Table 1). The MRI scan was performed by the same examiner and MRI slices were carefully selected. A thick MRI slice for the axial MRI was used to reduce the impact of differences of a slice dimension on hydration profile of the disc.

Participants

A total of 22 asymptomatic individuals were recruited by advertising in a local university. Inclusion criteria included no history of low back pain and no contraindication for a MRI scan. Exclusion criteria were: (1) movement loss of the back or lateral deformity of the spine, which was evaluated by the author; or (2) lumbar disc degeneration (Grades III–V⁸), which was evaluated by an orthopedic surgeon experienced in MRI with the sagittal T1- and T2-weighted images over the thoracic and lumbar spine and the axial T2-weighted images of the central portion of the lumbar disc from L1/L2 to L5/S1 in supine position. Two individuals (30-year old woman and 29-year old man) were excluded owing to a degenerated lumbar disc (Grade III). Mean (SD) age of the 20 participants (10 males) was 24.8 (4.0) years.

This study was approved by Shinoro Orthopedic, Japan and the institutional human medical ethics committee of Research Ethics Committee of the Society of Physical Therapy Science, Japan. A written consent was obtained before data collection. This study was registered in University Hospital Medical Information Network Clinical Trial Registry (UMIN000011987).

Procedure

The participant was first placed in a supine position beneath the flexible receiver surface coil (MR-JCL-72 separate type, HITACHI Inc. Sapporo, Japan), and the sagittal T1- and T2-weighted images, the coronal T1-weighted images and the axial T2-weighted images were obtained in neutral. Then, the participant was scanned in end range left SB and end range left SG positions. The order of these two test positions was randomly allocated and a 30-minute rest in lying was given between the MRI scans in the two test positions. In each test position, the pelvis was firmly stabilized to the measurement table with straps to prevent rotation of the pelvis.

For the MRI scan in the left SB position, the participant performed maximum SB and then one assistant applied overpressure manually through the shoulders to achieve end range and held the position during the MRI scan. Another assistant also held the knees during the scan to minimize movement artifact. The same assistants were involved during all MRI scans.

Before the MRI scan was conducted in a simulated SG position in lying, each participant experienced an end range SG in standing,⁹ which was performed by the author (a credentialed MDT therapist). During the MRI scan, the left SG position was created passively in lying, where glide force was adjusted based on participant's feedback to simulate the end range SG in standing. Figure 1 illustrates the SG position during the MRI scan. Briefly, the participant was positioned in supine next to a wooden pillar. The participant's right elbow was flexed and the arm was located beside the trunk. Folded towels were placed between the wooden pillar and the arm. The patient's pelvis was passively pushed to the wooden pillar and stabilized by a belt while one assistant maintained a line through the shoulders perpendicular to the sagittal plane. Both feet of the participant were fixed at 30 cm offset to left from the sagittal plane.

Image analysis

Segmental angles

For the measurement of lateral flexion and rotation angles at each segment of the lumbar spine during SB and SG, coronal T1-weight images covering from L1 vertebra to base of the sacrum and axial T1-weighted images through the bony vertebrae of L1 to S1 were

Table 1 Magnetic Resonance Imaging (MRI)* settings

Images	Field of view	TR/TE (ms)	Thickness (mm)	Interval (mm)	Scan time
Sagittal T1	300	385/24.5	6.0	7.0	5:45
Sagittal T2	300	2640/125	6.0	7.0	5:48
Coronal T1	320	400/16.0	4.0	5.0	6:24
Axial T1	300	450/19.3	8.0	8.0	5:46
Axial T2	260	312/120	8.0	8.0	6:52

*Fast spin echo was used.

Figure 1 Simulated left side gliding (SG) position during magnetic resonance imaging (MRI) scan.

captured. The same landmarks (Fig. 2) and method of angle calculation as previously reported² were utilized with the use of ImageJ software (version 1.6) (National Institute of Mental Health, Bethesda, MD, USA). Briefly, lateral flexion and rotation angles in the SB and SG positions were calculated as the difference between the angles in each measurement position from those in neutral at each vertebra. Left lateral flexion and rotation were expressed as positive and right lateral flexion and rotation were expressed as negative. Following this, segmental angles were calculated by subtracting the values of the lower vertebrae from those of the upper vertebrae. For the measurement of the segmental lateral flexion angles, the four corners of each vertebral body from L1 to L5 were identified. Subsequently, the midlines of each vertebra, which were defined as lines running through the midpoints between the two anterior and the two posterior corners, were drawn and the values between these lines and the axial plane were calculated. At the S1 level, a line parallel to the base of sacrum was used. To measure a segmental rotation angle, a line from the spinous process of each vertebra to the midpoint of the vertebral body (L1–L5) and a line

Figure 2 Landmarks of the measurement of segmental lateral flexion and rotation angles. (A) landmarks of four corners of each vertebral body from L1 to L5 and right and left edge of the base of sacrum. (B) landmarks of the spinous process and the center of each vertebra. (C) landmarks of the sacral promontory and the middle point of the S1 body.

connecting the sacral promontory with the middle point of the S1 body were drawn. The values between these lines and the sagittal plane were calculated. Measurements were repeated twice, on separate occasions, and the values were averaged. Those intra-class correlation coefficients (ICC) were considered good¹⁰ (segmental lateral flexion: 0.74–0.98, segmental rotation: 0.77–0.97).

Disc hydration shift

For the assessment of the disc hydration shift over the axial plane, the axial T2-weighted images of the central portion of the disc from L1/L2 to L5/S1 were obtained and each disc image was cored using generic software (Paint, Microsoft windows XP). Figure 3 demonstrates the procedures used. Specifically, a 55-pixel wide line was drawn along the coronal direction through the center of the disc using the ImageJ 1.6 software (National Institute of Mental Health, Bethesda, MD, USA). Middle points of pixel intensity lines (%), where these divide the total pixel intensity into equal halves on either side (right/left and anterior/posterior), were calculated over the mid-sagittal and mid-coronal planes. The differences of the mid-point values (%) in each plane between the supine position and the SB or SG position were computed and were plotted on a *X–Y* coordinates plane (i.e. shifted position of the disc hydration over the axial plane). The angle (theta) of the plotted point from the *X*-axis (theta, ranging from -180 to 180°) and the length of the plotted point from the origin of the *X–Y* coordinates plane (i.e. magnitude of shift) were calculated. These measurements were taken twice. The mean of those measurements was used

Figure 3 Schema of the procedures used to calculate theta values. Blue point: mid-point in the neutral supine position. Gray point: mid-point in the side gliding (SG) position. Red arrow: shift of disc hydration.

for statistical analyses. A pilot study recruiting 10 healthy individuals has shown that this method would produce ICC values greater than 0.80.

Statistics

Paired *t*-tests were used to compare: (1) the mean segmental angles of the lateral flexion and rotation; (2) the mean values of the differences in the mid-point values over the sagittal and coronal planes; and (3) the mean theta values and magnitude of the disc hydration shift, between the SB and SG positions at each level as data normality was confirmed by Shapiro–Wilk tests. Effect size was also calculated using Hedges's *g*¹¹ (large effect: 0.8, medium effect: 0.5, and small effect: 0.2). Statistical analyses were performed using SPSS. Statistical significance was set at $P < 0.05$.

Results

The mean segmental lateral flexion angles and rotation angles at each lumbar segment in the SB and SG are presented in Table 2 and Table 3, respectively. Only the segmental lateral flexion angle

Table 2 The mean (SD) segmental lateral flexion angles (degrees) at end-range side bending (SB) and side gliding (SG) positions to the left and effect sizes (Hedges's *g*) of the difference between the two positions.

Level	Side bending	Side gliding	<i>P</i> -value	Hedges's <i>g</i>
L1/L2	5.1 (2.2)	2.1 (2.7)	<0.001	1.19
L2/L3	6.7 (2.2)	6.1 (2.0)	0.14	0.28
L3/L4	6.9 (1.7)	6.6 (1.8)	0.44	0.17
L4/L5	6.6 (3.0)	5.8 (1.8)	0.11	0.32
L5/S1	5.4 (3.8)	4.1 (2.7)	0.11	0.39

Absolute values are presented for the effect size.

Figure 4 Shifted points of the disc hydration at L1/L2 at left side bending (SB) and side gliding (SG) positions. Abbreviations: A: Anterior; P: Posterior; R: Right; L: Left. Values are demonstrated in percentage of the anterior-posterior and right-left diameters of the disc. No significant difference ($P=0.94$, $g=0.05$) in the mean [SD] of the difference in the mid-point values in the sagittal direction between the SB (0.5 [2.2]) and SG (0.4 [2.0]). No significant difference ($P=0.13$, $g=0.37$) in the mean [SD] of the difference in the mid-point values in the coronal direction between the SB (3.5 [3.1]) and SG (2.3 [3.3]). No significant difference ($P=0.53$, $g=0.37$) in the mean [SD] of the theta values between the SB (6.5° [61.2°]) and SG (-18.0° [67.7°]). No significant difference ($P=0.50$, $g=0.22$) in the mean [SD] of the magnitude of disc hydration shift between the SB (4.6 [2.5]) and SG (4.1 [1.9]).

at L1/L2 had a statistically significant difference between SB and SG ($P<0.001$, $g=1.19$). Shifted positions of the disc hydration in the left SB and SG positions at each disc level are presented in Figs. 4–8. Notably, the disc hydration shifted to the right in the left SB and left SG positions. Between the SB and SG positions, there was no significant difference (a $P>0.05$) in the amount of motion and effect sizes were small, at most, in any measures.

Discussion

This is the first study to investigate the mechanical influence to each lumbar disc in response to the SG position using the shift of disc hydration. There was no significant difference in mean theta values between

Table 3 The mean (SD) segmental rotation angles (degrees) at end-range side bending (SB) and side gliding (SG) positions to the left and effect sizes (Hedges's g) of the difference between the two positions.

Level	Side bending	Side gliding	P -value	Hedges's g
L1/L2	0.1 (2.1)	0.0 (2.1)	0.87	0.05
L2/L3	1.2 (2.1)	0.7 (1.7)	0.34	0.26
L3/L4	0.3 (1.6)	0.4 (1.6)	0.81	0.06
L4/L5	0.4 (2.0)	-0.1 (1.6)	0.23	0.27
L5/S1	0.9 (3.1)	-0.4 (2.0)	0.06	0.49

Absolute values are presented for the effect size.

Figure 5 Shifted points of the disc hydration at L2/L3 at left side bending (SB) and side gliding (SG) positions. Abbreviations: A: Anterior; P: Posterior; R: Right; L: Left. Values are demonstrated in percentage of the anterior-posterior and right-left diameters of the disc. No significant difference ($P=0.74$, $g=0.05$) in the mean [SD] of the difference in the mid-point values in the sagittal direction between the SB (-0.4 [1.8]) and SG (-0.5 [2.4]). No significant difference ($P=0.41$, $g=0.19$) in the mean [SD] of the difference in the mid-point values in the coronal direction between the SB (4.8 [3.3]) and SG (5.4 [3.0]). No significant difference ($P=0.12$, $g=0.37$) in the mean [SD] of the theta values between the left SB (16.3° [35.7°]) and SG (3.0° [35.2°]). No significant difference ($P=0.25$, $g=0.34$) in the mean [SD] of the magnitude of disc hydration shift between the left SB (5.3 [3.0]) and SG (6.0 [2.8]).

SB (ranging from -15.1 to 16.3°) and SG (ranging from -18.0 to 4.7°) at all disc levels and effect sizes were also small (ranging from <0.01 to 0.37). This would be simply because the shift of disc hydration in an atypical direction, despite the small magnitude of the shift, can substantially affect mean values of theta. Therefore, in addition to statistical considerations of theta values, visualization of shifted position in the disc hydration over the axial plane (Figs. 4–8) and statistical investigations of mean values of the differences in the mid-point values over the sagittal and coronal planes are considered useful. From both the statistical investigations and observations of the shifted position in the disc hydration, the direction and magnitude of the disc hydration shift were considered comparable between the SB and SG positions although there was a difference in the lumbar alignment at L1/L2.

The results of the present study offer three points for consideration. First, these findings support a finding by Fazey *et al.*² that there is no significant correlation between the degree of lateral flexion and the magnitude of the disc hydration shift. Second, the results indicate that the maneuver of SG produces a comparable mechanical influence to lumbar discs,

Figure 6 Shifted points of the disc hydration at L3/L4 at left side bending (SB) and side gliding (SG) positions. Abbreviations: A: Anterior; P: Posterior; R: Right; L: Left. Values are demonstrated in percentage of the anterior-posterior and right-left diameters of the disc. No significant difference ($P=0.56$, $g=0.17$) in the mean [SD] of the difference in the mid-point values in the sagittal direction between the SB (-0.3 [1.5]) and SG (-0.6 [2.0]). No significant difference ($P=0.89$, $g=0.05$) in the mean [SD] of the difference in the mid-point values in the coronal direction between the SB (6.4 [2.1]) and SG (6.5 [1.8]). No significant difference ($P=0.55$, $g=0.13$) in the mean [SD] of the theta values between the left SB (2.5° [14.1]) and SG (4.7° [18.4]). No significant difference ($P=0.67$, $g=0.10$) in the mean [SD] of the magnitude of disc hydration shift between the left SB (6.6 [2.1]) and SG (6.8 [1.8]).

when compared with SB and that these two positions may be interchangeable in terms of joint alignment and the influence on the disc except at the L1/L2 segment. This would appear to validate the use of SG rather than SB in the MDT system's physical assessment. Third, the results may suggest that the choice to use SG rather than SB in MDT may be related to safety considerations rather than biomechanical considerations. Side bending in standing is not as stable as SG and patients with low back, with or without leg, pain may have difficulty controlling a load in the lateral direction during SB. In contrast, SG is achieved by leaning against a wall while placing an elbow and forearm between the trunk and the wall. Hence, it would be easier to control the magnitude of a patient's movement during SG, as opposed to SB, suggesting that SG may be a safer intervention. This hypothesis would need to be investigated in a future study.

This study showed minimal differences in mechanical influences to the disc between the static SB and SG positions. However, such minimal differences may be enhanced by repeated SB and SG movements owing to cumulative effects. This hypothesis would be clinically important as repeated SG is more

Figure 7 Shifted points of the disc hydration at L4/L5 at left side bending (SB) and side gliding (SG) positions. Abbreviations: A: Anterior; P: Posterior; R: Right; L: Left. Values are demonstrated in percentage of the anterior-posterior and right-left diameters of the disc. No significant difference ($P=0.83$, $g=0.05$) in the mean [SD] of the difference in the mid-point values in the sagittal direction between the SB (0.0 [1.9]) and SG (-0.1 [2.0]). No significant difference ($P=0.10$, $g=0.32$) in the mean [SD] of the difference in the mid-point values in the coronal direction between the SB (5.0 [2.2]) and SG (5.7 [2.1]). No significant difference ($P=0.98$, $g<0.01$) in the mean [SD] of the theta values between the left SB (1.6° [20.7]) and SG (1.7° [21.5]). No significant difference ($P=0.08$, $g=0.31$) in the mean [SD] of the magnitude of disc hydration shift between the left SB (5.3 [2.3]) and SG (6.0 [2.1]).

frequently used than sustained SG in clinical practice. Further investigations will be required to determine if a cumulative effect on the disc hydration shift exists.

There was a significant reduction of the segmental lateral flexion angle at L1/L2 in the SG position compared to SB. Mulvein and Jull⁷ compared movements of the L1 vertebra against the L4 vertebra and segmental movement at L5/S1 between SB and SG using motion sensors. Those researchers reported that the lateral flexion angle of the L1 vertebra, as opposed to the L4 vertebra, is less in SG than SB. This partially corresponds with the finding in the current study although the current study provided more specific information about segmental movements than Mulvein and Jull.⁷ Both the previous and current studies determined that there was no difference in the two movements at L5/S1. This is not surprising since SG generates movements through the pelvis, which would result in reaching end range at the lower segments earlier.

With respect to the SB position, segmental lumbar movements in the current study were partially different from those reported in previous studies.^{12,13} Previous studies measured segmental lateral flexion angles of the lumbar spine in standing using radiography. The

Figure 8 Shifted points of the disc hydration at L5/S1 at the left side bending (SB) and side gliding (SG) positions. Abbreviations: A: Anterior; P: Posterior; R: Right; L: Left. Values are demonstrated in percentage of the anterior–posterior and right–left diameters of the disc. No significant difference ($P=0.45$, $g=0.16$) in the mean [SD] of the difference in the mid-point values in the sagittal direction between the SB (0.4 [3.1]) and SG (−0.1 [2.9]). No significant difference ($P=0.32$, $g=0.37$) in the mean [SD] of the difference in the mid-point values in the coronal direction between the SB (1.6 [2.3]) and SG (2.5 [2.5]). No significant difference ($P=0.13$, $g=0.33$) in the mean [SD] of the theta values between the left SB (−15.1° [62.1°]) and SG (3.7° [48.0°]). No significant difference ($P=0.63$, $g=0.14$) in the mean [SD] of the magnitude of disc hydration shift between the left SB (3.7 [1.9]) and SG (4.0 [2.2]).

previous studies demonstrated smaller segmental ranges of motion at L4/L5 and L5/S1 than the current study. Such differences may be explained by the non-weight bearing MRI position used in the current study. Contraction of the erector spine muscles is required in standing and can influence spinal segmental movements.^{14,15} Thus, it may be expected that segmental movements of the lumbar spine in standing^{12,13} would be more limited than those shown in the current study.

Limitations

This study has five potential limitations. First, the results in this study were obtained in lying. In the MDT system, SG is performed in standing for an evaluation and treatment. Hence, the direction and magnitude of disc hydration shift observed in the current study may be different than in standing. The magnitude of mechanical influence to the disc is likely to be greater in standing than lying owing to the added compression forces of gravity. Second, caution is required in generalizing the findings in this study to the clinical setting as the shift of disc hydration was assessed in static positions. Repeated SG, which is more frequently used than sustained SG in clinical practice, may result in different mechanical responses

of the disc. Third, the current study included only healthy individuals without macroscopic degenerative changes on MRI. Beattie *et al.*¹⁶ suggested that movements of the nucleus pulposus would become less predictable when disc degeneration is present. Side bending and side gliding appear to produce the same hydrostatic, mechanical response from the disc in normal individuals. However, this does not guarantee that the direction and magnitude of movement of the nucleus pulposus in people with low back pain would be the same. Fourth, this study used a cross-over design with random allocation of the order of the two lumbar positions but the appropriateness of the 30-minute wash-out period is uncertain. Fifth, *a priori* sample size calculation was not undertaken in this study. A definite conclusion may be made when a larger sample size is used that is based on an appropriate power analysis. Therefore, this study should be considered as a foundation for future investigations of the disc's hydrostatic response.

Conclusion

It appears that the shift in lumbar disc hydration, in response to either static SB or SG, is comparable in a small sample of healthy individuals. Further studies are needed to evaluate these findings in a larger and more diverse sample.

Acknowledgements

The author wish to acknowledge Yuki Sasaki, MD, for inspection of the MRIs; Yoshikazu Ikemoto, MD, PhD, for providing facilities; and Chris Chase, PT, Dip. MDT for peer-reviewing before paper submission; and also is grateful to Shouta Kaneko, OT, M.Sc.; Yuta Nakai, JT, AA; and Kozue Nishimura, JT, AA, for their assistance in this project.

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