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Effects of Pelvic Asymmetry and Low Back Pain on Trunk Kinematics During Sitting: A Comparison With Standing

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Study Design. A prospective study was conducted on a group of patients with unilateral nonspecific low back pain (LBP) and healthy controls.

Objectives. To answer 3 questions: (1) Does pelvic asymmetry measured in standing affect the dynamics of motion performed in sitting? (2) Do patients with LBP perform trunk motions differently from non-LBP participants in sitting position? and (3) Do the kinematics of lateral flexion and axial rotation differ between sitting and standing positions?

Summary of Background Data. The effect of pelvic asymmetry on trunk motion while sitting remains unclear. LBP has been associated with altered trunk kinematics in standing; however, there is limited information available describing trunk kinematics in sitting position in comparison to standing.

Methods. Pelvic asymmetry was measured in 54 patients with unilateral nonspecific LBP and 59 control subjects. A motion-analysis system was used to test the range and symmetry of lateral flexion and axial rotation in sitting and standing positions. Bivariate correlations, regression, multivariate analysis of variance, and paired sample *t* tests were used to test for associations between variables and differences between groups.

Results. We found significant: (1) correlations between pelvic asymmetry and asymmetric trunk motion performed in sitting, (2) differences between the LBP and control groups in patterns of trunk motion performed in a sitting posture, and (3) differences between kinematics of motions performed in sitting *versus* standing postures.

Conclusions. This study shows a link between pelvic asymmetry and altered trunk motion in sitting position. We suggest that people with LBP may have a distinct compensatory mechanism, secondary to pelvic asymmetry, which puts the lumbar spine under higher stress. Movement asymmetry, rather than range of motion, may be a better indicator of disturbed function for people with LBP. Structural and functional asymmetries are factors that may be considered in the seating design and work environment.

Key words: pelvic asymmetry, low back pain, posture, sitting, trunk motion. **Spine 2006;31:E135–E143**

Low back pain (LBP) has long been connected to postural and structural asymmetries, most commonly in the pelvis.[1–3] Pelvic asymmetry refers to asymmetric pelvic alignment, with respect to the vertical axis, in the frontal or sagittal planes.[4] Pelvic asymmetry in the sagittal plane, namely, iliac rotation asymmetry, is often linked to sacroiliac joint dysfunction, and refers to malalignment between the left and right innominate bones.[5] This malalignment could either be unilateral anterior or posterior rotation of 1 innominate bone or bilateral contramovement of the innominate bones when both innominates rotate in opposite directions.[6] In the frontal plane, failure of the pelvis to lie in a perfectly horizontal position[7] is commonly called lateral pelvic tilt.

It is presumed that pelvic asymmetry alters the body mechanics, puts various body segments under strain, and, therefore, contributes to musculoskeletal pain.[8–12] In particular, compensation for pelvic asymmetry that occurs in the musculoskeletal system alters the mechanics of the lumbar spine as reflected, for example, by altered movement patterns in standing position.[13] However, what remains unknown is whether the effect of pelvic asymmetry on trunk mobility that is observed in standing is also present in sitting. Therefore, 1 of the aims of this study was to ascertain whether pelvic asymmetry correlates with altered trunk motion in the sitting position.

Changes in trunk kinematics during standing were also linked to nonspecific low back pain (NSLBP), which is also referred to as mechanical LBP.[14] This pain is defined as self-reported pain that is referred to the lower back, buttock, and/or thigh, and varies with time and movement, and in which neurologic and radiating pain symptoms are not present.[15] We wanted to know if NSLBP is also associated with altered kinematics in sitting. Altered trunk kinematics in sitting might potentially affect performance of functional tasks in this common position. It is presumed that trunk movement differs between sitting and standing because of the different initial posture of the lumbar spine: normally lordotic in standing, and semiflexed in sitting.

It is also believed that altered alignment of the spine affects spinal coupling (*i.e.*, motion in plane other than that of the voluntary motion).[16–19] Abnormal coupling may be an indicator of spinal dysfunction.[20] To our knowledge, the differences in trunk kinematics between sitting and standing have not been thoroughly investigated in patients with NSLBP and with respect to pelvic asymmetry.

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The main objective of this study was to assess the effect of a common postural asymmetry, namely, pelvic asymmetry, on trunk kinematics during sitting. To perform this assessment, we looked at asymmetry of trunk motion because it gives an insight into the adaptive changes that occur in the spine secondary to pelvic asymmetry. More specifically, we wanted to know if asymmetric trunk motion in sitting is associated with pelvic asymmetry, more evident in patients with NSLBP than in control subjects, and different from movement asymmetry in standing. We also examined if the coupled motion differs between standing and sitting. We were particularly interested in coupling between lateral flexion and axial rotation (*i.e.*, movements in the frontal and transverse planes). Because referred LBP distribution is often asymmetric,[21] we carefully selected a sample of patients with NSLBP who had predominantly unilateral NSLBP.

■ Methods

Participants. A total of 113 volunteer subjects (aged 20–45 years) were included in the study and classified into 2 groups. The LBP group included 27 males and 27 females (mean age ± standard deviation [SD] 33.4 ± 7.2 years) with predominantly unilateral nonspecific LBP. The control group included 25 males and 34 females (mean age ± SD 31.1 ± 6.9 years) with no previous history of LBP. Exclusion criteria included history of fracture, surgery, or congenital anomalies in the spine, pelvis, or lower limb, recent trauma, tumor, vestibular disease, or pregnancy. The Dalhousie University Health Sciences Human Research Ethics Board approved the study, and all volunteers gave their informed consent to participate.

We invited local physiotherapy clinics to refer subjects diagnosed with NSLBP (pain that varies with physical activity and time), recruiting those who obtained medical advice for their LBP in the 6 months before the study. LBP subjects were further screened using a questionnaire, and were carefully selected to have unilateral pain in the lumbosacral region, buttocks, and thigh with no nerve root symptoms (*e.g.*, pain radiating below the knee, numbness, or paresthesia).

Static Testing. For the pelvic measurement, the anterior superior iliac spines (ASISs) and posterior superior iliac spines (PSISs) were palpated and marked with skin markers (8 mm in diameter and marked in the center). We then used an anthropometric measuring frame to obtain the width and height of the ASISs' and PSISs' height from the floor and width apart, with participants in a standing position.[22] There were 3 measurements per side taken, and averages were used for the analysis. We conducted a pilot study involving 10 subjects to examine the reliability of our static measures. Intra-class correlation coefficients[23] ranged between 0.83 and 0.95.

Dynamic Testing. First, the subject's back was exposed from the level of the sacrum up to the occiput, and reflective markers (13 in total) were applied on: the spinous processes of the first and sixth thoracic vertebrae (T1 and T6); the first and fifth lumbar vertebrae (L1 and L5); 3 markers on the sacrum, including 2 medial to the PSISs and 1 marker at the sacral apex; and 3 pairs of paravertebral markers at the lateral border of the erector spinae muscles at the levels of T1, T6, and L1. Data were collected using the Qualysis™ Motion Analysis System (Qualysis Medical AB, Gothenburg, Sweden) with 5 ProReflex™ motion capture units that were arranged in a semicircle around the subject so that each marker was visible for at least 2 cameras at every point of the movement. Motion data were processed using PC Reflex™ and custom software written in MatLab™ 6.5 (The MathWorks, Inc., Natick, MA). The accuracy of the Qualysis system has been reported elsewhere.[24]

Similar to the method proposed by Crosbie *et al*,[25] the trunk was divided into series of presumed rigid bodies or spinal regions: upper and lower thoracic, lumbar, and sacral regions (Figure 1). Local coordinate systems were established for each region based on the surface markers and the underlying anatomic landmarks. To measure relative spatial changes between adjacent spinal regions, we used the 3-dimensional coordinates of the anatomic landmarks and the classic mechanics technique of Cardan angles. The sequence of Cardan angles was chosen to correspond to the anatomic motion.[26]

We examined the kinematics of 2 trunk motions: lateral flexion, which is motion in the frontal plane, and axial rotation, which is motion in the transverse plane, in both standing and unsupported sitting postures. Subjects were asked to twist (axial rotation) or bend laterally (lateral flexion) from the neutral position to their extreme to 1 side, sweep uninterrupted to their extreme on the other side, then return to the initial neutral position. All movements started and finished in the upright neutral position, which was used as the starting "zero" position

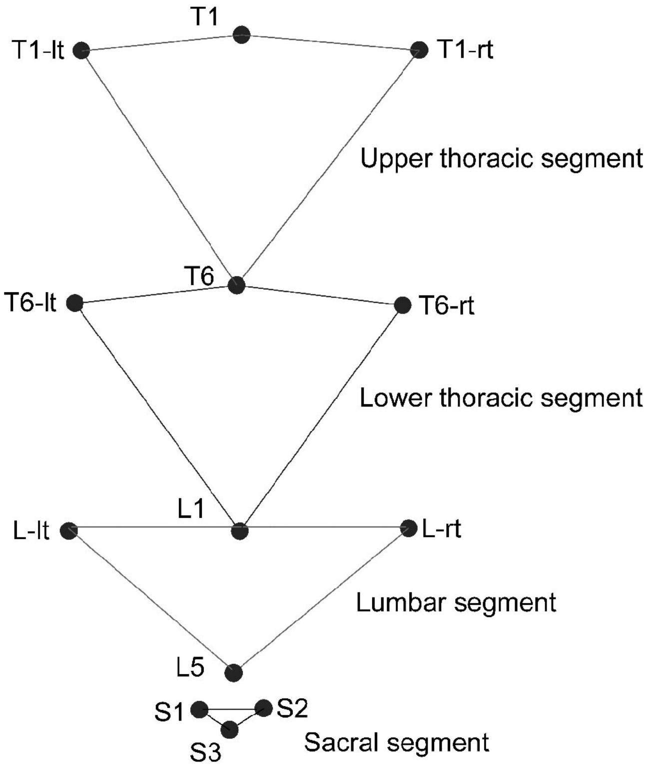

Figure 1. The construction of spinal regions using 13 reflective markers applied on the spinous processes of first thoracic (T1), sixth thoracic (T6), first lumbar (L1), and fifth lumbar (L5) vertebrae, 3 pairs of paravertebral markers (T1-lt, T1-rt, T6-lt, T6-rt, L-lt, L-rt), and 3 markers on the sacrum (S1, S2, and S3). Upper thoracic region was defined by T1, T6, T1-lt, and T1-rt. Lower thoracic region was defined by T6, L1, T6-lt, and T6-rt. Lumbar region was defined by L1, L5, L-lt, and L-rt. Sacral region was defined by S1, S2, and S3.

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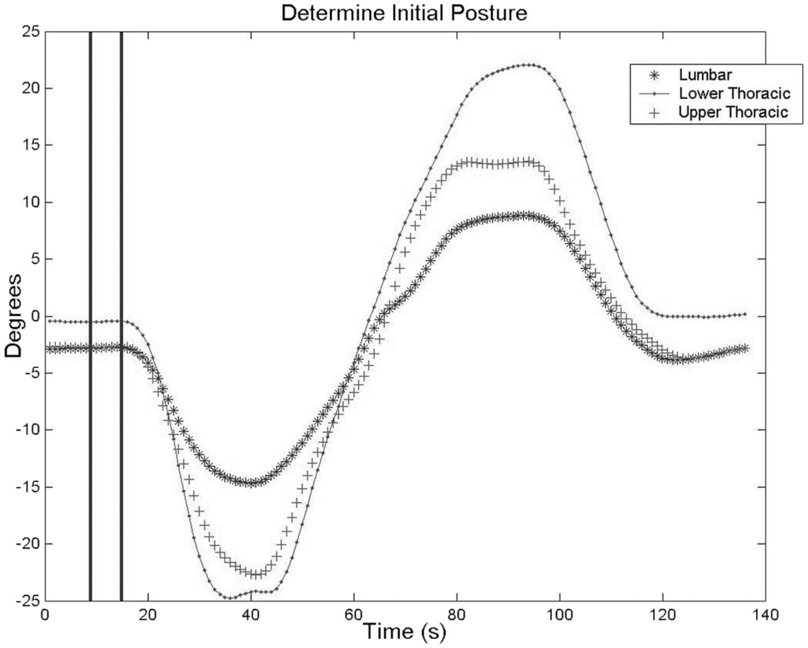

Figure 2. Plot of the angular displacements in the 3 regions (lumbar, lower, and upper thoracic) during a lateral flexion task from neutral to the right, left, and back to neutral. The area between the 2 vertical lines designated the initial posture, used as the zero position for each angle.

(Figure 2). These movements were at the subjects' own chosen speed (within a prescribed 10 seconds interval) and with their arms loosely crossed over the chest. Self-selected speed was chosen because it produces more reliable measures of trunk motion.[27] Furthermore, self-selected speed allows smoother and more controlled movement through full possible range without inducing sudden pain or antalgic movement. Each movement cycle was normalized to 100 data points, between the beginning and end of the movement, to enable comparisons. There were 3 trials of twists and lateral bends beginning to the right and 3 to the left executed in a randomized fashion. No significant differences were found between the ranges of movement in opposite direction. Therefore, we averaged the range of motion over 6 trials: 3 beginning to the right and 3 to the left.

The 3-dimensional spatial parameters of the markers were measured at a sampling frequency of 20 Hz, which is adequate to prevent aliasing error.[28–31] Features of motion extracted included maximum range of motion to the left, maximum range of motion to the right, and total range of motion from maximum left to maximum right. We conducted a preliminary analysis on a sample of 10 asymptomatic participants to evaluate the repeatability of the dynamic measurements. High values of intra-class correlation coefficient (0.84–0.95) indicated high reliability of our protocol.[23] Test-retest reliability on 2 different occasions was also acceptable (intra-class correlation coefficient 0.77–0.86), indicating consistent markers placement. Nevertheless, examining the raw data showed that scapular motion distorted the registered motion in the upper thoracic region. Thus, we report only on the movement in the lumbar and lower thoracic regions.

Quantification of Asymmetry. To derive a pelvic asymmetry measure, we used the following equation: pelvic asymmetry ratio = (ASIS height difference/ASIS width) + (PSIS height difference/PSIS width). This ratio defines the slope between the ASISs and PSISs in the frontal plane.[22] The ratio differentiates between the 2 most common types of pelvic asymmetry: (1) lateral pelvic tilt, in which both the ASIS and PSIS are higher on 1 side relative to the other, and where the anterior and posterior slopes would be parallel; and (2) iliac rotation asymmetry, in which on 1 side the ASIS is higher and the PSIS is lower than the other side, in which instance the 2 slopes intersect.[32] An advantage of this method of measurement is that it is normalized to each individuals' pelvic width. Accuracy and reliability of this method have been established.[32] To quantify trunk movement asymmetry, we divided the absolute difference in lateral flexion (or rotation) between the right and left sides by the total range from right to left: movement asymmetry = 100 [|right − left|/(right + left)].

Statistical Analyses. We used SPSS statistical software (version 10.1; SPSS, Inc., Chicago, IL). The Pearson product moment correlation coefficient was used to examine the relationship between pelvic asymmetry and asymmetry in movements performed in sitting position. Linear-regression analysis was conducted to evaluate whether pelvic asymmetry or pain predict movement asymmetry (dependent variable). Independent variables were pain status (categorical variable: LBP or non-LBP), pelvic asymmetry ratio (continuous variable), and classification of pelvic asymmetry (categorical variable: lateral pelvic tilt or iliac rotation asymmetry).

Using a multivariate analysis of variance (MANOVA), we tested whether there were significant differences between the subjects with LBP and the controls in 3 movement parameters: total range, absolute difference, and asymmetry. There were 4 MANOVA tests conducted: Pillai trace, Wilks lambda, Hotelling trace, and Roy largest root, which yielded similar results. We report only the value of the first test, the most robust of the 4 methods.[33,34] We looked for differences between the NSLBP and control groups in the principal motion, as well as the coupled (accompanying) motion. We also used the χ^2 test to assess differences between the groups in the direction of coupled motion. Paired sample t tests were used to assess differences between movements performed in sitting *versus* standing positions. Significance was assumed at 0.05 for all analyses.

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Table 1. Correlations Between Pelvic Asymmetry Ratio and Asymmetry in Movements Performed in Sitting Position

	Classification Based on Recruitment Process		Classification Based on Pelvic Asymmetry Measurement	
Principal Movement	Control (n = 59)	LBP (n = 54)	Lateral Pelvic Tilt (n = 62)	Iliac Rotation Asymmetry (n = 51)
Lumbar lateral flexion	0.437*	0.378*	0.518*	0.338†
Lumbar axial rotation	0.446*	0.394*	0.541*	0.318†
Thoracic lateral flexion	0.387*	0.178	0.218	0.090
Thoracic axial rotation	0.402*	0.087	0.374*	0.011

Values are the Pearson product moment correlation coefficient.
*Significant correlation is at 0.01.
†Significant correlation at 0.05.

Results

The following results are presented in the sequence outlined in the objectives listed in the Introduction. We note that all the results on thoracic motion are based on the lower thoracic region.

Pelvic Asymmetry and Trunk Motion in Sitting Position

Comparison Between NSLBP and Control Participants. Pelvic asymmetry was correlated with asymmetry in lumbar motion in both NSLBP and control groups, and was only correlated with asymmetry in thoracic motion in the control group (Table 1). Regression analysis indicated that pelvic asymmetry was significant ($P < 0.01$) in predicting asymmetry in lateral flexion ($R^2 = 0.24$) and axial rotation ($R^2 = 0.21$), while pain status was not ($P > 0.05$).

Comparison Between Types of Pelvic Asymmetry. The pelvic asymmetry ratios formed a continuum that ranged from 0.005 to 0.186. Hence, we considered that all subjects presented with varying degrees of subtle pelvic asymmetry. Therefore, we classified this asymmetry into 2 groups: a lateral pelvic tilt group, in which the ASIS and PSIS on 1 side were higher than the other side (n = 62); and an iliac rotation asymmetry group, in which the ASIS was higher and the PSIS was lower in 1 innominate compared to the other (n = 51). Pelvic asymmetry correlated with asymmetry in lumbar motion in both asymmetry groups: lateral pelvic tilt and iliac rotation (Table 1). On the other hand, pelvic asymmetry did not correlate with asymmetry in thoracic motion, except in the group of subjects with lateral pelvic tilt, in which pelvic asymmetry correlated with asymmetry in thoracic axial rotation.

LBP and Kinematics of Motion Performed in Sitting Position

Principal Movement. MANOVA revealed significant differences between the LBP and control groups in lateral flexion ($F_{(6106)} = 2.94$, $P = 0.01$), and axial rotation ($F_{(6106)} = 2.615$, $P = 0.02$). The mean values and SDs of the total range, absolute difference between the right and left range, and asymmetry of principal movement are presented in Table 2. Post hoc analysis indicated that the LBP group had significantly higher asymmetry in both lumbar lateral flexion and lumbar axial rotation (Table 2). There were no significant differences between the groups in the total range of lumbar motion. Although the LBP group showed reduced range of thoracic axial rotation, the groups did not differ in the symmetry of thoracic motion.

Coupled Movement. When lateral flexion was the principal motion, the LBP group had significantly higher asymmetry of coupled lumbar axial rotation (Table 3). There were no differences though between the groups in the range or amount of asymmetry in coupled motion for the thoracic region. Furthermore, when axial rotation was the main motion, the MANOVA result indicated there were no significant differences between the groups, therefore, we did not conduct post hoc analysis on those data (Table 3).

The groups showed similar coupling patterns except for lumbar coupling when the principal motion was axial rotation. Table 4 presents the frequency of subjects who had ipsilateral (same direction) *versus* those with contralateral (opposite direction) coupling. When lateral flexion was the main motion, coupled lumbar rotation was ipsilateral in 68% and 67% of the control and LBP groups respectively, and coupled thoracic rotation was also ipsilateral in 80% and 72% of the control and LBP groups. Conversely, when axial rotation was the primary motion, lumbar coupling was contralateral in 75% of the control group, and contralateral in 54% and ipsilateral in 46% of the LBP group. Furthermore, when axial rotation was the main motion, thoracic coupling was mainly contralateral (78% of controls and 63% of LBP group). An example of coupling pattern is presented in Figure 3.

Kinematics of Motion Performed in Sitting Versus Standing Positions (all subjects)

Principal Movement. The ranges of both lumbar and thoracic lateral flexion were significantly higher in standing, whereas ranges of lumbar and thoracic axial rotation were higher in sitting (Table 5). In addition, asymmetry in lumbar axial rotation was significantly higher in standing, while asymmetry in lumbar lateral flexion was comparable between sitting and standing. Asymmetry in

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Table 2. Results of the MANOVA for Differences Between the Control (n = 59) and LBP (n = 54) Groups in the Principal Movements Performed in Sitting Position

	Range (degrees)		Absolute Difference (degrees) |right − left|		Movement Asymmetry (%) [|right − left|/(right + left)]*100]	
Principal Movement	Mean ± SD	P	Mean ± SD	P	Mean ± SD	P
Comparisons in Lateral Flexion*						
Lumbar lateral flexion		0.195		0.002†		0.037†
Control group	16.1 ± 7.8		2.1 ± 2.0		18.7 ± 15.4	
LBP group	18.1 ± 8.6		4.2 ± 3.1		25.5 ± 18.7	
Thoracic lateral flexion		0.409		0.211		0.146
Control group	32.9 ± 8.2		2.0 ± 1.5		6.4 ± 5.2	
LBP group	31.7 ± 7.8		2.3 ± 1.7		8.1 ± 6.5	
Comparisons in Axial Rotation‡						
Lumbar axial rotation		0.071		0.026†		0.029†
Control group	35.6 ± 8.5		4.1 ± 3.6		11.8 ± 11.3	
LBP group	38.7 ± 9.3		5.8 ± 4.4		15.2 ± 11.8	
Thoracic axial rotation		0.029†		0.698		0.990
Control group	45.7 ± 12.1		3.7 ± 2.8		8.7 ± 7.6	
LBP group	41.0 ± 10.1		3.5 ± 2.4		8.7 ± 5.9	

*Multivariate test. Pillai trace value = 0.143, $F_{(6106)} = 2.940$, $P = 0.011$†.
†Significant difference.
‡Multivariate test. Pillai trace value = 0.129, $F_{(6106)} = 2.615$, $P = 0.021$†.

thoracic motion did not differ between sitting and standing, except for the absolute difference in lateral flexion (Table 5). However, when the absolute difference was normalized within the total range, there were no differences in asymmetry of lateral flexion between sitting and standing.

Coupled Movement. The range of coupled lateral flexion was significantly higher in sitting, while the range of coupled axial rotation was higher in standing (Table 6).

■ Discussion

This study provides objective evidence that relatively subtle skeletal asymmetry, and not just pathology, influences patterns of trunk movement. To our knowledge, the study is specifically the first to show a link between subtle pelvic asymmetry and altered trunk motion in sitting posture, and significant differences between patients with NSLBP and a group of controls in patterns of trunk motion performed in a sitting position. Our main conclusion is that functional compensation in the lumbar region caused by pelvic asymmetry in standing is also evident in sitting, indicating that the compensation results in functional alteration that is not corrected by leveling the pelvis on the sitting surface. Furthermore, it seems that the presence of NSLBP was associated with the nature of the compensation. Patients with NSLBP presented with more asymmetric movement patterns in the lumbar region that could be caused by both the pelvic asymmetry and LBP. On the other hand, pain-free participants had higher range of movement in the lower thoracic region that is more likely related to their pelvic asymmetry and adaptive spinal tissue changes.

Table 3. Results of the MANOVA for Differences Between the Control (n = 59) and LBP (n = 54) Groups in Coupled Movements Performed in the Sitting Position

	Range (degrees)		Absolute Difference (degrees) |right − left|		Movement Asymmetry (%) [|right − left|/(right + left)]*100]	
Coupled Movement	Mean ± SD	P	Mean ± SD	P	Mean ± SD	P
When Principal Motion is Lateral Flexion*						
Lumbar axial rotation		0.161		0.002†		0.001†
Control group	5.8 ± 2.5		1.2 ± 1.1		19.0 ± 15.5	
LBP group	6.7 ± 3.5		2.1 ± 1.9		30.0 ± 17.2	
Thoracic axial rotation		0.306		0.758		0.966
Control group	6.5 ± 3.0		1.7 ± 1.7		28.1 ± 26.8	
LBP group	6.0 ± 2.7		1.9 ± 1.8		28.0 ± 19.7	

*Multivariate test. Pillai trace value = 0.191, $F_{(6106)} = 4.184$, $P = 0.001$†.
†Significant difference.
When principal motion is axial rotation, the multivariate test is used with a Pillai trace value of 0.093, F = 1.819, *df* (6106), *P* = 0.102. Because of the lack of significant difference as indicated by MANOVA, post hoc analysis was not needed.

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Table 4. Frequency of Subjects Who had Contralateral *Versus* Those With Ipsilateral Coupling in Sitting Position

	Lumbar Coupling			Thoracic Coupling		
Principal Movement	Ipsilateral	Contralateral	*P*	Ipsilateral	Contralateral	*P*
Lateral flexion			0.629			0.240
Control group (n = 59)	40 (68%)	19 (32%)		47 (80%)	12 (20%)	
LBP group (n = 54)	36 (67%)	18 (33%)		39 (72%)	15 (28%)	
Axial rotation			0.017*			0.061
Control group (n = 59)	15 (25%)	44 (75%)		13 (22%)	46 (78%)	
LBP group (n = 54)	25 (46%)	29 (54%)		20 (37%)	34 (63%)	

The χ^2 tests performed on the 2 × 2 tables shows the number and percentages of subjects.
*Significant difference.

Pelvic Asymmetry and Trunk Motion in Sitting Position

Comparison Between LBP and Control Participants. Pelvic asymmetry has been linked to NSLBP.[1,35,36] It is a commonly held view that pelvic asymmetry leads to secondary altered alignment in the lumbar spine, such as scoliosis.[12] This altered alignment presents as a lateral curve that includes varying degrees of vertebral rotations as well. Generally, it is these secondary alterations that are presumed to contribute to LBP and lead to secondary structural alterations in the spine.[11] Such secondary scoliosis would explain why pelvic asymmetry was correlated with asymmetric lumbar motion in our sample. However, what is more interesting is the correlation between pelvic asymmetry and asymmetric thoracic motion that we found in the control group only. This result may indicate that compensation for pelvic asymmetry in the nonpatient population occurs in a larger portion of the trunk, in contrast to the patient group, in which compensation is confined in the lumbar region only. We wonder if this altered compensatory mechanism predisposes some individuals to NSLBP. It is worth investigating further whether subjects with NSLBP compensate for pelvic asymmetry with higher altered alignment in the lumbar region.

Comparison Between Types of Pelvic Asymmetry. Both iliac rotation asymmetry and lateral pelvic tilt were correlated with asymmetry in lumbar motion in sitting position. This result indicates that imbalances in the lumbar region associated with pelvic asymmetry in standing are retained in sitting. On the other hand, although lateral pelvic tilt had an impact on thoracic motion, iliac rotation asymmetry did not correlate with asymmetry in thoracic motion. Again, this effect might be related to differences in compensatory mechanisms that occur in the spine in response to the different types of pelvic asymmetry. Although iliac rotation asymmetry usually results in rotation of the lumbar vertebrae toward the posteriorly rotated ilium,[37] lateral pelvic tilt is often associated with compensatory functional scoliosis, with curvature convexity on the side of the shorter lower limb.[11,38] This compensatory scoliosis probably explains why lateral pelvic tilt was correlated with asymmetry in thoracic motion in our study.

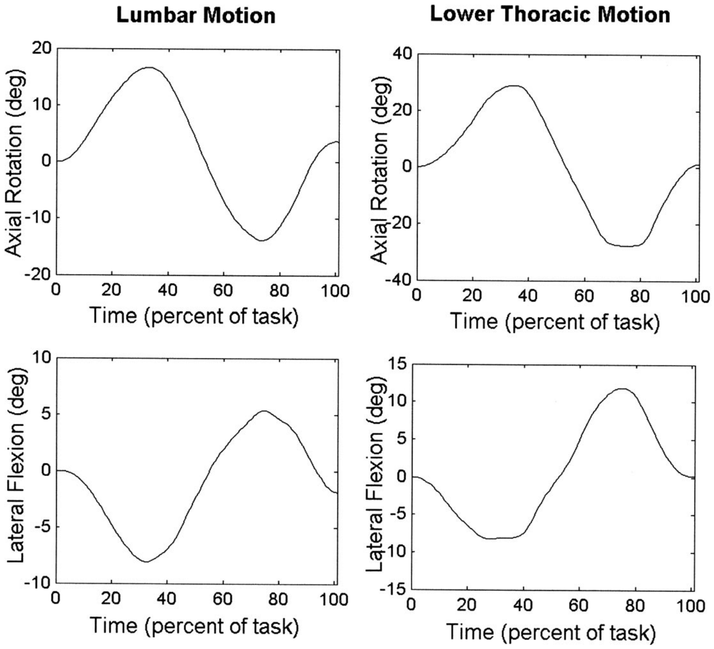

Figure 3. A subject performing axial rotation in sitting position. In this example, the subject rotates from neutral to the left, to the right, then back to neutral. The coupled motion, lateral flexion, was contralateral in both lumbar and lower thoracic regions.

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Table 5. Results of the Paired Sample *t* Tests for Differences Between Principal Movements Performed in Sitting *Versus* Standing Positions (n = 113)

	Range (degrees)		Absolute Difference (degrees) |right − left|		Movement Asymmetry (%) [(|right − left|/(right + left))*100]	
Principal Movement	Mean ± SD	*P*	Mean ± SD	*P*	Mean ± SD	*P*
Lumbar lateral flexion		0.001*		0.260		0.636
Sitting position	17.0 ± 8.2		2.3 ± 1.8		16.3 ± 12.7	
Standing position	20.4 ± 7.9		2.6 ± 2.2		15.5 ± 14.3	
Lumbar axial rotation		0.001*		0.004*		0.001*
Sitting position	37.1 ± 9.0		4.9 ± 4.1		13.4 ± 11.6	
Standing position	26.0 ± 7.6		6.6 ± 5.0		26.4 ± 20.4	
Thoracic lateral flexion		0.003*		0.016*		0.104
Sitting position	32.3 ± 8.0		2.1 ± 1.6		7.2 ± 5.9	
Standing position	34.8 ± 9.7		2.8 ± 2.2		8.5 ± 7.6	
Thoracic axial rotation		0.006*		0.967		0.536
Sitting position	43.4 ± 11.4		3.6 ± 2.6		8.7 ± 6.8	
Standing position	39.9 ± 14.2		3.9 ± 3.6		9.4 ± 9.0	

*Significant difference.

LBP and Kinematics of Motion Performed in Sitting Position

The second objective of the study was to test if patients with NSLBP perform motions differently from healthy subjects in the sitting position. Knowledge of patterns of motion in sitting would be of value in assessing patients with LBP. Our study provides normative data on trunk motion in the transverse and frontal planes.

Principal Movement. Although we did not find differences between the groups in the total range of lumbar motion in sitting, the LBP group clearly showed higher movement asymmetry. Considering this finding, it seems that asymmetry of motion may be a better indicator of abnormal functioning in the lumbar region than the range of motion. Although asymmetric trunk motion has been linked to LBP in standing position,[39,40] to our knowledge, this is the first study to show this link in a sitting position. The excessive movement asymmetry in the LBP group could imply that this group had a different trunk prerotation angle (*i.e.*, the initial trunk angle before starting movement) from the controls.

Table 6. Results of the Paired Sample *t* Tests for Differences Between the Ranges of Coupled Movements in Sitting *Versus* Standing Positions (n = 113)

	Range (degrees)	
Coupled Movement	Mean ± SD	*P*
Lumbar lateral flexion		0.001*
Sitting position	13.7 ± 6.5	
Standing position	7.8 ± 4.0	
Lumbar axial rotation		0.001*
Sitting position	6.2 ± 3.0	
Standing position	9.9 ± 4.8	
Thoracic lateral flexion		0.004*
Sitting position	11.7 ± 5.9	
Standing position	9.4 ± 5.7	
Thoracic axial rotation		0.001*
Sitting position	6.3 ± 2.9	
Standing position	9.1 ± 4.8	

Lateral flexion is the coupled motion when axial rotation is the principal motion, and vice versa.
*Significant difference.

Activities that involve twisting while in a seated posture are assumed to be risk factors for LBP.[41] Furthermore, although little muscle effort is required at the beginning 10° to 20° of axial rotation, increasing effort is required beyond that range to overcome stiffness of the osteoligamentous structures.[41,42] Therefore, the observed restriction of thoracic rotation in our LBP group could probably be a combination of guarding behavior and anatomic limitation.

In the literature, the reported range of lumbar axial rotation in a seated posture ranges between 35° and 80°.[41–43] This wide range is probably the result of differences in measurement procedures. Our results lie in the lower end of that range. Although we used a similar system to that of Torén,[41] we quantified trunk motion differently. Torén defined the twisting angle as that between 2 external frames, 1 applied on the shoulder and the other on the pelvis. On the other hand, we applied markers directly on the back and measured relative motion between consecutive spinal regions, which is closer to capturing true trunk movement.

Coupled Movement. Consistent coupling may be an important component of normal spinal function. Most researchers agree that coupling behavior is dependent on the posture and sagittal orientation (flexion/extension) of the spine.[16–19] To our knowledge, there are no studies on the coupling of lateral flexion and axial rotation in sitting posture among LBP populations.

In the sitting position, when axial rotation was the main movement, the majority of the control group showed contralateral lumbar coupling of side flexion, consistent with previous *in vivo*[44] and *in vitro*[18] findings. However, when lateral flexion was the main movement, coupled lumbar axial rotation was ipsilateral in the majority of our sample. Although this former result agrees with the *in vitro* findings

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of Vicenzino and Twomey,[45] it is partially in contrast with the *in vivo* findings of Vachalathiti *et al*.[44] This discrepancy may be the result of differences in how lumbar motion is described. We quantified the relative motion between a lumbar and a sacral embedded axis system. However, Vachalathiti *et al*[44] quantified lumbar motion as the relative motion between a lower thoracic and a pelvic embedded reference system, which potentially exaggerated the lumbar motion. The agreement between our study and *in vitro* studies gives further support to our results.

There are few data regarding the coupling pattern in the thoracic spine despite its possible association with scoliosis.[46] The most convincing evidence available indicates that, in the neutral posture, coupling between lateral flexion and axial rotation in the lower thoracic spine (T6–T12) is ipsilateral.[47] We showed that in a semiflexed posture, lateral flexion is coupled mostly with an ipsilateral rotation, and axial rotation is coupled mostly with opposite lateral flexion. We also observed distinct difference between our NSLBP group and the controls in coupling with axial rotation. Considering that the facet joints guide coupled motion,[48] altered pattern of coupling may indicate some abnormality in the facet joints. Our study adds to the reports on the association between LBP and axial rotation.[49,50]

We realize that coupling varies at intervertebral levels,[51] which we could not measure. However, we were interested in examining if consistent patterns of gross trunk motion are detectable using the noninvasive method described here. We also realize that the gross motion we measured is the product of summation of intersegmental motion. Despite its limitations, studying trunk movement *in vivo* using surface markers that span multiple segments provides a useful picture of both the osteoligamentous capability of the spine as well as the effect of the neuromuscular control system (*e.g.*, sensory feedback).

Kinematics of Motion Performed in Sitting Versus Standing Positions

Principal Movement. Although the posture in standing is less constrained than sitting, the range of axial rotation in sitting was significantly higher than in standing. This result may be explained by the anatomy of the lumbar facet joints, which are normally locked in extension and open in flexion. Sitting, which puts the lumbar spine in a semiflexed posture, puts the facet joints in a slightly less compact position and, thus, frees up the rotatory movement in the lumbar spine. Resistance from passive tissues (*e.g.*, tight ligaments) and limitation of pelvic motion may be behind the significantly lower range of lateral flexion in sitting compared to that in standing. Although asymmetry in lumbar axial rotation decreased in sitting, asymmetry in lateral flexion was similar in sitting and standing. This result supports the idea that leveling the pelvis on the sitting surface does not correct the associated secondary scoliosis.

Coupled Movement. White and Panjabi[46] indicated that coupled movements depend on many factors, such as the orientation of the facet joints, geometry of the individual vertebra, and spinal posture. Our results support the view that changes in the posture of the spine have a direct effect on coupled movements.[16,18] Interestingly, coupled lateral flexion increased and coupled axial rotation decreased in sitting compared to standing. This finding corresponds well with the ranges of principal motion: increased axial rotation and reduced lateral flexion. It seems that as the principal movement increased, coupled motion increased as well.

■ Conclusion

This study assists in the understanding of the association between NSLBP and pelvic asymmetry. The observed effects of pelvic asymmetry on trunk function that we report here should be of value to clinicians and health professionals involved in the treatment of LBP. Knowledge of compensatory motions assists in the understanding of the effects of pelvic asymmetry on function. Considering the current findings, we suggest that asymmetry of motion as we measure it (*i.e.*, normalized to correct for different ranges) is possibly a better indicator of abnormal functioning in the back than the absolute range of motion itself. In addition, the considerable similarities in the total range of lumbar motion between the control and LBP groups gives further reason to use normalized data.

From an ergonomics prospective, symmetric trunk posture and function are often presumed in seating design and lifting guides. Our results suggest that pelvic asymmetry influences trunk motion in sitting. However, it remains unclear whether such asymmetry warrants correction of the sitting surface. One previous study suggested the use of pre-ischial bars to correct gross pelvic asymmetry in persons in wheelchairs.[52] Our study has provided a basis for further research on pelvic asymmetry and asymmetric trunk movements to establish whether modified seat design can reduce the occurrence of NSLBP in people who regularly work in a seated setting.

■ Key Points

- Asymmetry of trunk motion is a better indicator of functional alteration in the back than the absolute range of motion.
- Compensatory functions that occur in the trunk secondary to pelvic asymmetry, such as asymmetric movement patterns, are not corrected by leveling the pelvis in sitting.
- Functional compensation to pelvic asymmetry involves not only changes in lumbar motion but also changes in the thoracic region.
- Patients with LBP had altered movement patterns when performing axial rotation in seated position, which may be related to the higher amount of rotation allowed in sitting compared to standing.

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