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Effects of Pelvic Skeletal Asymmetry on Trunk Movement

Three-Dimensional Analysis in Healthy Individuals *Versus* Patients With Mechanical Low Back Pain

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Study Design. Comparative analysis and correlational research design were used to investigate the association between anthropometry and biomechanical performance among asymptomatic subjects and patients with low back pain (LBP).

Objectives. To examine the association between pelvic asymmetry and patterns of trunk motion in asymptomatic and LBP subjects. Secondary objective was to investigate the association between restricted trunk motion, laterality of referred pain, and pelvic asymmetry.

Summary of Background Data. Subtle pelvic asymmetry (exhibited as either lateral pelvic tilt or iliac rotational asymmetry), which is common among normal individuals, has not been convincingly linked to abnormalities in back movements. Given the difficulty in diagnosing most LBP, a classification using pelvic asymmetry and patterns of movement could be helpful in establishing a rational treatment plan.

Methods. Fifty-nine subjects with no history of LBP and 54 patients with mechanical unilateral LBP were tested. An anthropometric frame was used to measure pelvic asymmetry in standing. Dynamic motion data, comprised of the principal and coupled movements, were collected using the Qualysis Motion Capture System.

Results. While the groups did not differ in the total range of lumbar movement, the LBP group exhibited significantly higher asymmetry in the principal motion. The groups differed significantly in the pattern of coupled rotation during lateral flexion. Asymmetry in lumbar lateral flexion was highly related to two types of pelvic asymmetry: lateral pelvic tilt (LPT) and iliac rotation asymmetry (IRA). Asymmetry in lumbar axial rotation was highly related to IRA but weakly related to LPT.

Conclusions. This study demonstrates objective differences in patterns of lumbar movement between asymptomatic subjects and patients with LBP. The study also demonstrates that subtle anatomic abnormality in the pelvis is associated with altered mechanics in the lumbar spine. We suggest that asymmetry of lumbar movement may be a better indicator of functional deficit than the absolute range of movement in LBP.

Key words: pelvic asymmetry, trunk kinematics, low back pain, coupling. **Spine 2006;31:E71–E79**

Sixty to eighty percent of the general adult population suffers low back pain (LBP) at some point in their lives.[1,2] LBP is also the major cause of disability for patients under the age of 45 in the United States.[3,4] The high cost of LBP can be attributed to its high incidence, high recurrence, and associated disability.

Back pain is a symptom rather than a disease diagnosis.[5] Almost 80% of patients with LBP do not have structural pathologic changes (*e.g.*, radiologic signs of degeneration, or intervertebral disc herniation). Such patients are classified as having "nonspecific" or "mechanical" LBP, defined as pain in the back that is induced and aggravated by mechanical factors such as movement.[6] Currently, functional assessment is the only way to differentiate between various forms of mechanical LBP. Such assessment is particularly important in patients with LBP since pain avoidance and the adaptation to pain that take place in the musculoskeletal system may lead to functional deficits,[7] such as abnormal movement patterns.[8]

Spinal mobility is widely used as an objective clinical assessment of LBP, for both diagnostic and progress evaluation purposes, despite its poor sensitivity and specificity.[9,10] While some studies reported a significant difference in spinal mobility between healthy participants and patients with LBP,[10,11] more recent studies found no significant difference between those two populations in spinal mobility.[9,12] This lack of agreement may be attributed to differences in measurement procedures, methods of analysis, and study populations.

Furthermore, there is great variability in trunk motion among both asymptomatic and patient populations,[13] and no general consensus on what constitutes normal trunk motion. Pathology in the low back might affect the pattern of movement rather than only the range of movement.[14] Hence, assessment of movement symmetry could indicate abnormality in spinal motion and give some insight to underlying dysfunction.

In particular, asymmetries of trunk lateral flexion and axial rotation are presumed to be clinically important.[15–17] Asymmetry in lateral flexion is useful for identifying subtle lateral lumbar shift,[15,18] especially in cases of lumbar disc herniation.[19] Also, trunk axial rotation is one of the common movements often affected by LBP.[20,21]

Trunk axial rotation and lateral flexion are associated with each other, a phenomenon known as "spinal cou-

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pling."[22–25] Coupling is best defined as motion in which rotation or translation of a body about or along one axis is consistently associated with simultaneous rotation or translation about another axis.[26] Using biplanar radiography, excessive coupled motion accompanying flexion-extension movement has been reported in asymptomatic subjects[27] and in patients with LBP.[11] Coupling characteristics are essential elements in the understanding of spinal kinematics; however, the clinical significance remains obscure.

Although asymmetric movement in the back has been reported,[15] factors and constraints that might lead to such asymmetry in either normal or patient populations are not well understood. In this study, we examine whether or not asymmetry in trunk motion is associated with pelvic skeletal asymmetry, a condition commonly linked to LBP.[28–30] Pelvic structural asymmetry is associated with soft tissue changes in the back as well as with compensatory postures.[31] Hence, if people adapt to pelvic asymmetry over time, interventions to correct the asymmetry, such as shoe lifts, may not be necessary. However, if the pelvic asymmetry leads to altered movement patterns that might negatively affect the individual's activities, then there is a need to better understand this association to develop appropriate interventions. To date, the association between pelvic asymmetry and altered spinal movement remains unclear in both symptomatic and asymptomatic populations.[32]

We conducted this study to examine if patients with LBP had identifiable movement patterns, such as movement asymmetry, that were different from those of asymptomatic individuals. We then tested if movement asymmetry was related to pelvic asymmetry. Another objective was to compare between asymptomatic individuals and patients with LBP in the magnitude and direction of the coupled (accompanying) motion in the frontal and transverse planes. Furthermore, since referred pain distribution is often asymmetric,[33] we also examined the association between the laterality in asymmetric movement and laterality of referred pain.

■ Methods

Participants. Volunteers (males and females, 20–45 years of age) were recruited locally through poster and media advertisement. Informed consent for the study was granted by the University Health Sciences Human Research Ethics Board. All potential participants were initially screened for eligibility over the phone. Subjects were excluded if they had a history of vestibular disease, spinal fracture, spinal inflammatory disease, recent trauma, tumor, developmental anomalies in the back or limbs, or postural hypotension. Pregnancy from the first trimester to 1 year postpartum also excluded the subject.

We invited local physiotherapy clinics to refer subjects diagnosed with mechanical LBP (defined as pain that specifically 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 pain (*e.g.*, pain radiating below the knee, numbness or paresthesia).

Table 1. Descriptive Profiles of the Two Study Groups

Variable	Control (n = 59)	LBP (n = 54)	*P*
Age (yr)	31.1 ± 6.9	33.4 ± 7.2	0.084
Weight (kg)	68.8 ± 14.5	77.1 ± 14.2	0.003†
Height (cm)	169.8 ± 8.7	170.7 ± 9.0	0.591
BMI (kg/m^2)	23.7 ± 3.5	26.3 ± 3.6	0.001†
Pelvic asymmetry	0.046 ± 0.03	0.066 ± 0.04	0.001†

Means (±SDs) of age, weight, height, body mass index (BMI), and pelvic asymmetry ratio for subjects in the study, and the *P* values for differences between the control and LBP groups.
†Significant difference.

A total of 143 subjects were initially screened; however, after applying our inclusion/exclusion criteria, 113 subjects were included in the study and classified into two groups: control group with no history of LBP in the 12 months before the study (n = 59: 25 males and 34 females, mean age ± SD = 31.1 ± 6.9 years), and LBP group with predominantly unilateral mechanical LBP (n = 54: 27 males and 27 females, mean age ± SD = 33.4 ± 7.2 years). Descriptive profiles of the subjects are presented in Table 1.

Equipment. To assess pelvic asymmetry, a measuring frame was used to obtain the width and height of the anterior and posterior superior iliac spines, with participants in a standing position.[34] The accuracy of the frame was previously tested and high reliability was reported[35] with intraclass correlation coefficient ($ICC_{1,1}$) values that exceeded 0.94.

To measure trunk kinematics, we used the Qualysis Motion Capture System (Qualysis Medical AB, Gothenburg, Sweden), which consists of five ProReflex motion capture units and lightweight reflective surface skin markers. The ProReflex units emit infrared beams that are reflected off the surface markers back to the units. [Each marker had to be visible for at least two cameras at every point of the movement, for units to provide three-dimensional coordinates for the marker.] PC Reflex software was used to reconstruct a moving three-dimensional image of the subject. The accuracy of the Qualysis system has been reported elsewhere.[36]

Thirteen spherical reflective markers were applied on the back of each subject, over the spinous processes of the first and sixth thoracic vertebrae (T1, T6), first and fifth lumbar vertebrae (L1, L5), the sacrum at three points (sacral apex and two markers medial to the posterior superior iliac spines), and three pairs of paravertebral markers at the lateral borders of the erector spinae muscles at the levels of T1, T6, and L1 (Figure 1). Similar to the method proposed by Crosbie *et al*,[37] the trunk was divided into series of rigid bodies or series of spinal segments: sacral, lumbar, lower, and upper thoracic. Software was developed in MATLAB (The MathWorks, Inc., Natick, MA) to establish a local coordinate system based on surface markers and the underlying anatomic landmarks. We measured spatial changes in the regions of the spine by calculating the relative motion between adjacent spinal segments using classic mechanics technique of Euler angles.[38] The sequence of Euler angles was chosen to correspond to the anatomic motion. In this study, we report on the movement in the lumbar and lower thoracic segments.

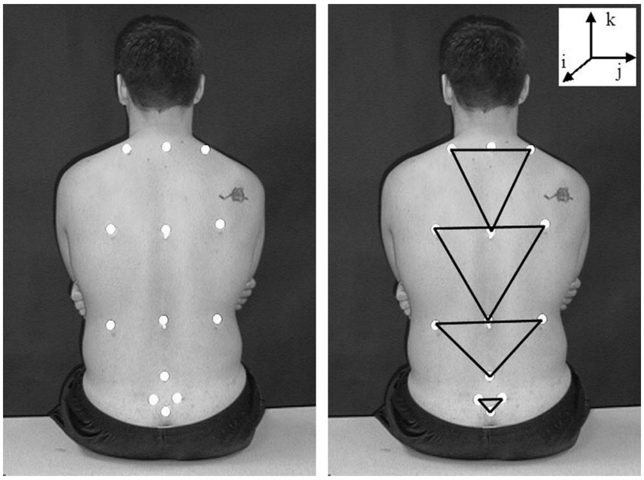

Figure 1. A participant with 13 markers attached and the four rigid bodies used to model the spine: sacral, lumbar, lower, and upper thoracic. **a**, The 13 markers attached to the back. **b**, The four triads constructed from the markers, and the three orthogonal axes: k, vertical; j, mediolateral; and i, anteroposterior.

Procedure. Before collecting data, each subject was familiarized with the equipment and given a description of the testing protocol and an informed consent form. Information about hand and leg dominance, age, weight, height, and body mass index, was obtained from each subject. Subjects with LBP were asked to fill out a questionnaire (about the side and duration of symptoms) to generally define their LBP and categorize them, although not all of these data were used in this study. The study was specifically restricted to two types of pelvic asymmetry: iliac rotation asymmetry and lateral pelvic tilt (the latter being commonly associated with anisomelia). The test session consisted of measurement of pelvic asymmetry followed by dynamic testing. Three sets of measurements were taken for each subject's anterior superior iliac spines (ASISs) and posterior superior iliac spines (PSISs) height from the floor and width apart, and the mean values were used to calculate a pelvic asymmetry ratio.

For dynamic testing, we examined the kinematics of motion while the subject performed two trunk motions: lateral flexion and axial rotation at a sampling frequency of 20 Hz. This frequency was appropriate given that the movements were relatively slow.[14,39–41] Lateral flexion was defined as rotation in the frontal plane about the x-axis (anteroposterior), and axial rotation as rotation in the transverse plane about the z-axis (vertical).

Subjects were instructed to stand as erect as possible with feet apart in a wooden foot frame (to ensure standardization of neutral position), and their arms loosely crossed over the chest. Each subject was instructed to laterally flex (or rotate) from the neutral position as far as possible (to his/her endpoint) to one side, sweep uninterrupted to the other side, then return to the erect stance, and to avoid bending forward or backward while performing the movement. Although we encouraged the participants to move as far as possible, we allowed them to choose their own pace, similar to performing tasks in real life, since preferred speed has been shown to produce more reliable measures of torso motion than predetermined speed.[42]

The order of movement direction (starting left or right) was randomized for each subject. The subject performed three trials of each movement direction (right first or left first), for a total of 12 motion sets. A 60-second rest period was given between trials.

Kinematic Variables. The original starting position (subject standing still at the beginning of each trial) was used as the baseline from which we measured asymmetry. Motion in the frontal and transverse planes was displayed graphically as a curve of angular displacement over time. Figure 2 shows a typical graphical output for a lateral flexion task with coupled axial rotation. Since each participant performed the movement at their own pace, we normalized each plot to 100 data points, between the beginning and end of movement, to enable comparisons. The apexes of the curve represent the maximum range, positive to the left and negative to the right. Features of motion extracted included: maximum range to the left (L), maximum range to the right (R), and total range of motion from maximum left to maximum right.

We conducted a preliminary analysis on a sample of 10 normal participants to evaluate the repeatability of the dynamic measurements. High values of intraclass correlation coefficient (ICC = 0.84–0.95) indicated high reliability of our protocol.[43] Test-retest reliability on two different occasions was also acceptable (ICC = 0.77–0.86) indicating consistent markers placement.

Quantification of Asymmetry. To describe pelvic asymmetry, we used a pelvic asymmetry ratio (PAR) that defines the slope between the ASISs and the slope between the PSISs,[35] as follows:

$$\text{PAR} = (\text{ASIS height diference/ASIS width}) + (\text{PSIS height diference/PSIS width})$$

This method enabled us to differentiate between the two most common types of pelvic asymmetry: 1) frontal plane asymmetry commonly known as lateral pelvic tilt, in which one innominate bone is higher or lower than the other innominate, and 2) sagittal plane asymmetry known as iliac rotation asym-

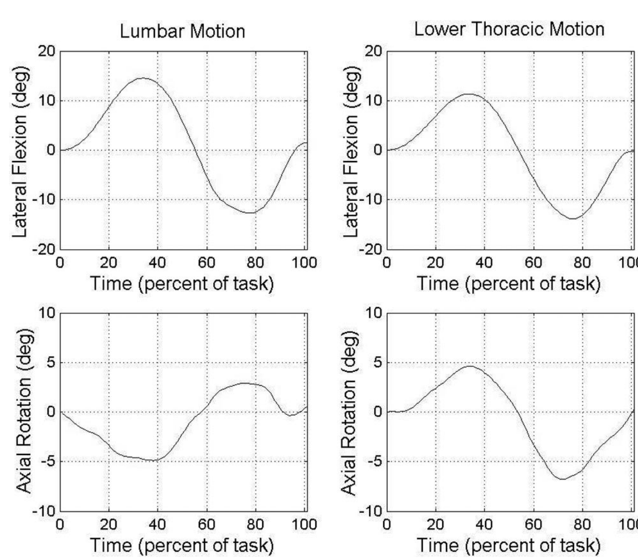

Figure 2. A typical graphical output of a subject performing a lateral flexion task from neutral standing to the left, to the right, and back to neutral. Coupling of axial rotation with lateral flexion was contralateral in the lumbar region and ipsilateral in the lower thoracic.

Table 2. Results of the Multivariate ANOVA for Differences Between the Control (n = 59) and LBP (n = 54) Groups in the Principal Motion

		Range (°)		Absolute Difference (R − L) (°)		Movement Asymmetry (%) [R − L/(R + L)] × 100	
Principal Movement	Group	Mean ± SD	*P*	Mean ± SD	*P*	Mean ± SD	*P*
Lumbar lateral flexion	Control	21.1 ± 7.7	0.401	2.2 ± 1.7	0.016*	12.5 ± 11.2	0.023*
	LBP	19.8 ± 8.1		3.1 ± 2.5		18.6 ± 16.6	
Lumbar axial rotation	Control	26.1 ± 7.1	0.858	5.1 ± 4.3	0.001*	20.4 ± 17.7	0.001*
	LBP	25.9 ± 8.2		8.2 ± 5.3		32.9 ± 21.2	
Thoracic lateral flexion	Control	36.8 ± 8.5	0.020*	3.0 ± 2.0	0.185	8.4 ± 5.3	0.823
	LBP	32.6 ± 10.6		2.5 ± 2.4		8.7 ± 9.6	
Thoracic axial rotation	Control	42.8 ± 14.7	0.024*	3.5 ± 4.5	0.792	8.2 ± 8.3	0.143
	LBP	36.8 ± 13.1		3.7 ± 3.3		10.7 ± 9.6	

*Significant difference.

metry, in which one innominate bone rotates anteriorly or posteriorly relative to the other innominate.[34] An important advantage of this method is that the PAR is normalized to each individual's pelvic width.

To quantify trunk movement asymmetry, we divided the absolute difference in lateral flexion (or axial rotation) between the right and left sides by the total range from right to left. In other words, to get a percentage of the movement asymmetry within the total range of movement, we used the following equation: Movement asymmetry = 100 [|R − L|/(R + L)].

Statistical Analyses. Data were analyzed using SPSS 10.1 Statistical Analysis Package. Multivariate analysis of variance (MANOVA) and χ^2 tests were used to examine differences between the control and LBP groups. Statistical significance was assumed at the 0.05 level. Pearson Product Moment Correlation Coefficient (r) was calculated to examine the association between pelvic asymmetry and movement asymmetry. We also conducted Fisher's exact test and binary logistic regression to determine the effect of side of pain (right *vs.* left) and type of pelvic asymmetry (lateral pelvic tilt *vs.* iliac rotation asymmetry) on the side of restricted motion.

■ Results

Table 1 summarizes the characteristics of the study population. The LBP group had significantly higher weight and body mass index than the control group, but the groups did not differ in their age and height. The pelvic asymmetry ratio was also significantly higher in the LBP group. Unfortunately, the effect of handedness on performance asymmetry could not be investigated because of the small number of left handed individuals (n = 17) *versus* the far greater number of right handed individuals (n = 96) in our sample.

Principal Motion

The means of the total range, absolute difference, and asymmetry in voluntary lateral flexion and axial rotation are presented in Table 2. The LBP group had significantly greater asymmetry in lumbar lateral flexion and lumbar axial rotation when these movements were the principal motions. The LBP group had significantly reduced range of thoracic lateral flexion and axial rotation as principal motions. The groups did not differ in the range of lumbar motion, or in the asymmetry of thoracic motion.

Coupled Motion

The LBP group exhibited significantly higher range and asymmetry in lumbar coupled axial rotation, but not in lumbar coupled lateral flexion (Table 3). There were no significant differences between the groups in the range and asymmetry of thoracic coupled motion. Table 4 shows the number of subjects that exhibited ipsilateral (same direction) coupling *versus* those with contralateral (opposite direction) coupling of axial rotation with lat-

Table 3. Results of the Multivariate ANOVA for Differences Between the Control (n = 59) and LBP (n = 54) Groups in the Coupled Motion

		Range (°)		Absolute Difference (R − L) (°)		Movement Asymmetry (%) [R − L/(R + L)] × 100	
Coupled Movement	Group	Mean ± SD	*P*	Mean ± SD	*P*	Mean ± SD	*P*
Lumbar lateral flexion	Control	7.9 ± 4.2	0.776	2.3 ± 1.6	0.814	32.7 ± 22.0	0.921
	LBP	7.7 ± 3.7		2.3 ± 1.8		33.1 ± 25.5	
Lumbar axial rotation	Control	8.9 ± 4.2	0.024*	2.4 ± 2.5	0.013*	23.6 ± 18.7	0.009*
	LBP	11.0 ± 5.2		4.0 ± 3.7		34.0 ± 22.8	
Thoracic lateral flexion	Control	8.6 ± 4.3	0.106	2.2 ± 1.9	0.213	30.2 ± 25.8	0.461
	LBP	10.3 ± 6.8		2.7 ± 1.9		33.9 ± 25.7	
Thoracic axial rotation	Control	9.6 ± 5.2	0.242	2.7 ± 2.3	0.464	32.1 ± 26.3	0.766
	LBP	8.6 ± 4.2		2.4 ± 1.9		30.7 ± 25.4	

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

Table 4. Direction of Coupled Motion

		Lumbar Coupling			Thoracic Coupling		
Principal Movement	Group	Ipsilateral	Contralateral	*P*	Ipsilateral	Contralateral	*P*
Lateral flexion	Control (n = 59)	15 (25%)	44 (75%)	0.007*	41 (70%)	18 (30%)	0.542
	LBP (n = 54)	27 (50%)	27 (50%)		38 (70%)	16 (30%)	
Axial rotation	Control (n = 59)	24 (41%)	35 (59%)	0.158	33 (56%)	26 (44%)	0.081
	LBP (n = 54)	28 (52%)	26 (48%)		39 (72%)	15 (28%)	

Frequency of subjects who showed contralateral *versus* those with ipsilateral coupling. Chi-square tests performed on the 2 × 2 tables showing the no. and percentages of subjects.
*Significant difference.

eral flexion. When the principal motion was lateral flexion, χ^2 test indicated significant difference ($P = 0.007$) between the groups in the direction of coupling; the majority of subjects in the control group (75%) had opposite coupled axial rotation, as opposed to 50% of the LBP group. χ^2 test also indicated that the direction of thoracic coupling did not differ between the groups ($P > 0.05$), with the majority of subjects showing ipsilateral coupling. The groups did not differ in the lateral flexion coupling when axial rotation was the principal motion (Table 4).

Association Between Pelvic Asymmetry and Movement Asymmetry

Values of Pearson Product Moment Correlation Coefficient revealed high correlation between pelvic asymmetry and asymmetry in lumbar lateral flexion in both groups (Table 5). Pelvic asymmetry and asymmetry in lumbar axial rotation had weak significant correlation in the control group but were not correlated in the LBP group. Pelvic asymmetry did not correlate with asymmetry in thoracic motion, except in the LBP group where pelvic asymmetry correlated with asymmetry in thoracic lateral flexion.

Classification Based on Pelvic Asymmetry Ratio

Since the pelvic asymmetry ratios formed a continuum (Figure 3) that ranged between 0.005 and 0.186, we considered all subjects asymmetric and classified them into two asymmetry groups; a lateral pelvic tilt (LPT) group in which the ASIS and PSIS on one side were higher than the other side (n = 62), and an iliac rotation asymmetry (IRA) group in which the ASIS was higher and the PSIS was lower in one innominate compared with the other (n = 51).

Table 5. Correlations (r) Between Pelvic Asymmetry and Movement Asymmetry Within the Control and LBP Groups

Principal Movement	Normal (n = 59)	LBP (n = 54)
Lumbar lateral flexion	0.713*	0.834*
Lumbar axial rotation	0.437*	0.191
Thoracic lateral flexion	0.150	0.448*
Thoracic axial rotation	0.164	0.054

Values are Pearson Product Moment Correlation Coefficients.
*Significant correlation at $P < 0.01$.

Pelvic asymmetry was highly correlated with lumbar lateral flexion asymmetry in the LPT and IRA groups (Table 6). The correlation between pelvic asymmetry and asymmetry in lumbar rotation was high in the IRA group but low in the LPT group.

Association Between Side of Radiating Pain, Restricted Movement, and Pelvic Asymmetry

Within the LBP group (n = 54), there were 28 subjects with lateral pelvic tilt and 26 subjects with iliac rotation asymmetry. Table 7 shows that of the lateral pelvic tilt group, 11 subjects had higher right ilium and 17 subjects had higher left ilium. In the iliac rotation asymmetry group; 14 subjects had a posteriorly rotated right ilium and 12 subjects had posteriorly rotated left ilium. Ninety-one percent of patients with lateral pelvic tilt higher on the right had a restricted left lateral flexion and 73% of them had restricted right lumbar rotation. On the other hand, 77% of patients with lateral pelvic tilt higher on the left had restricted right lateral flexion and 94% of them had restricted left axial rotation. All patients with right posteriorly rotated ilium had restricted rotation on the left, while all those with left posteriorly rotated ilium had restricted right rotation. Fisher's exact test showed that the side of pelvic tilt was significantly associated with the side of restriction in both lateral flex-

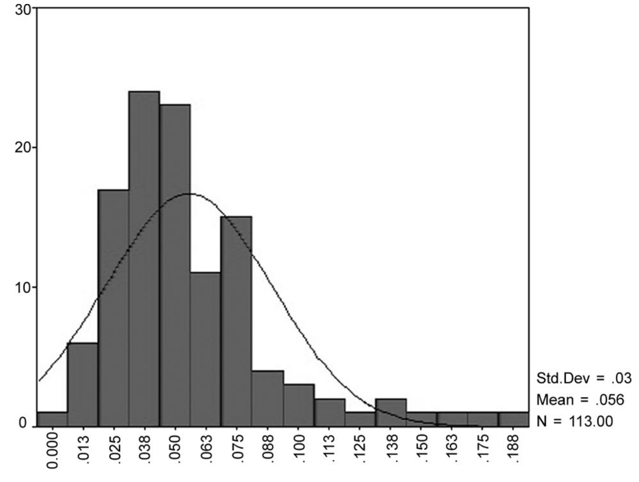

Figure 3. Distribution of pelvic asymmetry ratios of the entire sample (n = 113).

Table 6. Correlations (r) Between Pelvic Asymmetry and Movement Asymmetry Within the Asymmetric Groups and Iliac Rotation Asymmetry and Lateral Pelvic Tilt Groups

Movement	Iliac Rotation Asymmetry (n = 51)	Lateral Pelvic Tilt (n = 62)
Lumbar lateral flexion	0.819†	0.808†
Lumbar axial rotation	0.714†	0.288†
Thoracic lateral flexion	0.329*	0.388†
Thoracic axial rotation	0.199	0.072

Values are Pearson Product Moment Correlation Coefficients.
*Significant correlation at $P < 0.05$.
†Significant correlation at $P < 0.01$.

ion and axial rotation. On the other hand, the side of iliac rotation was significantly associated with restriction in axial rotation but not so with restriction in lateral flexion.

Logistic regression indicated that classification of patients based on the laterality and direction of pelvic asymmetry (*i.e.*, lateral pelvic tilt or iliac rotation asymmetry) was a significant predictor of restricted motion ($P < 0.05$), while side of referred pain was not. As far as we are aware, such findings using normalized data have not been reported in the literature.

■ Discussion

This study demonstrates objective differences in patterns of lumbar movement between normal subjects and those with mechanical LBP that have no other gross conspicuous asymmetry. The LBP group had significantly higher lumbar motion asymmetry than the control group, but the groups did not differ in asymmetry of thoracic motion. The patient group also had abnormal patterns of coupled rotation with lateral flexion in the lumbar region. Based on these results, it appears that asymmetry in lumbar lateral flexion and axial rotation effectively distinguishes between healthy individuals and patients with unilateral mechanical LBP. Furthermore, our results indicate that altered mechanics in the lumbar spine is associated with subtle anatomic abnormality in the pelvis.

There is a lack of agreement on how to characterize the type and degree of LBP.[9,15,44] This lack of agreement may be, in part, due to the diversity in the LBP population studied; *e.g.*, patients with varied diagnostic and surgical histories. In our study, we carefully selected a homogeneous patient group with a common pattern of LBP in which the pain was unilateral and above the knee (referred pain, not radiating) and whose pain was position/motion and time dependent, commonly described as mechanical LBP.

For patients that have no identifiable radiologic abnormality, trunk kinematics appear to be useful indicator of biomechanical performance. However, reliable and sensitive measures of trunk kinematics are crucial in such cases. Most of the techniques that are commonly used clinically are subjective and, hence, lack accuracy and reliability.[45] Our results on coupling characteristics agree with three-dimensional radiographic measurements[24,46]; hence, we think that the method we used to quantify trunk motion accurately describes gross trunk movement. Also, the magnitude of the peak and total range of principal motion we observed are consistent with the ranges presented in previous studies.[14,39]

Previous studies that failed to discriminate between normal subjects and LBP patients did not quantify motion of the lumbar and lower thoracic spine separately (*e.g.*, Masset *et al*[12]). Hindle *et al*[14] observed that most of the differences between LBP subjects and matched controls occurred in lateral flexion and axial rotation, but these differences did not reach statistical significance. We found that the control subjects had significantly higher range of thoracic motion than the LBP subjects, but there was no difference between the groups in the lumbar total range of motion. The reduced range of thoracic motion in the LBP group observed in our study may be due to compensatory behavior to avoid pain.

In contrast with our findings, some researchers reported that there are no significant differences in spinal motion between left and right flexion and axial twist in normal subjects.[14,47] As well, few studies have attempted to quantify trunk movement asymmetry in subjects with LBP.[15,48] Gomez[15] defined a symmetry ratio as a percentage deviation from unity of the ratio of right to left range of motion $\{[(R/L) - 1] \times 100\}$; however, the outcome of the former symmetry ratio depends on the choice of the numerator, right *versus* left. The asymmetry measure we used seems more meaningful as it takes the total range of motion into account, and gives the asymmetry as a percentage of the range, hence normalizing the asymmetry to each individual's performance.

Table 7. Classification of Subjects in the LBP Group (n = 54) Based on Their Pelvic Asymmetry Ratios and the Side of Restricted Motion Right (R) or Left (L)

		Restricted Lateral Flexion			Restricted Axial Rotation		
Pelvic Asymmetry	N	R	L	*P*	R	L	*P*
R pelvic tilt	11	1 (9%)	10 (91%)	0.001*	8 (73%)	3 (27%)	<0.001*
L pelvic tilt	17	13 (77%)	4 (23%)		1 (6%)	16 (94%)	
R ilium posterior rotation	14	11 (79%)	3 (21%)	0.133	0	14 (100%)	<0.001*
L ilium posterior rotation	12	6 (50%)	6 (50%)		12 (100%)	0	

Values are no. and percentages of subjects, and the results of Fisher's exact test applied to each 2 × 2 table.
*Significant difference.

Our results partially agree with Gomez[15] who also reported significantly greater movement asymmetry in lateral flexion in a group of LBP subjects compared with normal subjects. Gomez,[15] however, reported no significant difference between the groups in axial rotation.

Although the literature reveals an association between LBP and altered spinal movement, it is still not known whether the altered movement is related to pain or some underlying structural asymmetry in the musculoskeletal system. It is possible that asymptomatic subjects may not necessarily possess an ideal physical structure and, hence, may demonstrate altered biomechanical performance or movement patterns.[15] We think that movement asymmetry reflects restriction or stiffness in either vertebral or paravertebral structures. Our results suggest that asymmetry in lumbar movement is highly associated with pelvic asymmetry in the normal population.

On the other hand, in the LBP group, pelvic asymmetry was associated with asymmetry in lateral flexion, but not with asymmetry in axial rotation. Asymmetry in rotation in the LBP group may be due to protective guarding, increase in apprehension, or asymmetric pain distribution rather than gross tissue constraints. Some authors suggest that twisting of the trunk is one of the most common movements triggering LBP.[21,49] Our results agree with previous reports that restricted rotation is commonly associated with LBP.[15,50]

The few previous studies that investigated the influence of pelvic asymmetry on lumbar spine kinematics focused mainly on the frontal plane asymmetry; lateral pelvic tilt, which is commonly caused by leg length discrepancy (LLD). Mincer *et al*[51] suggested that LLD does not influence trunk flexion and extension. Conversely, simulating LLD in a group of asymptomatic subjects using 2.5-cm heel raise under the left heel resulted in significantly reduced right lateral flexion and increased left lateral flexion, but had no significant effect on axial rotation.[52] Assessing leg length, however, as frequently described in the literature, does not take into account the adaptations that occur in the pelvis. Although it is often hypothesized that LLD correlates with lateral pelvic tilt (asymmetry in the frontal plane), LLD also correlates with iliac torsion (asymmetry in the sagittal plane).[32] In other words, an asymmetry in the length of the lower limb could manifest itself in the pelvis as a lateral pelvic tilt or iliac torsion or a combination of both. Hence, in the current study, we chose to assess the position/orientation of the anterior and posterior superior iliac spines to differentiate between lateral pelvic tilt and iliac rotation. Previous research revealed that LBP correlates with pelvic asymmetry,[28] which provides further reasoning for assessing pelvic asymmetry instead of LLD. Furthermore, we chose to assess pelvic asymmetry in both asymptomatic and patient populations, in order to capture the cumulative effects of real anatomic asymmetry, rather than acute effects of artificially induced leg length asymmetry (such as placing blocks under one limb[52]). Our results suggest that pelvic asymmetry alters the distribution of forces and tissue loading in the lumbar spine, as reflected by the altered kinematics associated with it.

In this study, a lateral pelvic tilt higher on the right was associated with restricted left lateral flexion and restricted right axial rotation, and *vice versa*. This is in agreement with the common belief that LPT is often associated with compensatory functional scoliosis with curvature convexity on the side of the shorter leg.[53,54] On the other hand, rotational asymmetry in the pelvis, *i.e.*, iliac rotation asymmetry, resulted in asymmetric axial rotation but had no effect on lateral flexion. According to Lee,[55] an iliac rotation asymmetry usually results in rotation of the lumbar vertebra, probably toward the posteriorly rotated ilium. This is further confirmed by our results, where a right posteriorly rotated ilium was associated with restricted left axial rotation, and *vice versa*.

One of the unresolved issues in spinal kinematics is "coupling," as there is controversy regarding coupled motions that take place when the main motion is either lateral flexion or axial rotation (for a review, see Harrison *et al*[56]). We found that the LBP group had greater range and asymmetry in coupled axial rotation than the control group. The groups also differed in the direction of lumbar coupling. Thus, it appears that LBP affects coupling behavior, which may in turn be due to ipsilateral or contralateral protective spasm or early disc pathology as well as pelvic skeletal asymmetry. This fact may have implications for clinicians who use lumbar spine manipulation to treat LBP. Our results also support the view that, starting from the neutral position of a normal lumbar spine, the coupling of lateral flexion with rotation occurs in opposite directions.[57]

An accurate determination of the presence and direction of restricted trunk motion is essential to guide treatment in the clinical setting. Studies on the association between movement restriction, lateral pelvic tilt, and laterality of LBP symptoms indicate inconsistent results. It is assumed clinically that pain can be provoked if the patient bends toward the convexity of "sciatic scoliosis."[58] In a group of subjects with LLD of 5 mm or greater, those who reported sciatica were symptomatic on the side of the longer limb 75% of the time,[59] while in 60% of a sample of patients with herniated disc, the pain radiated in the shorter limb.[60] Other researchers reported that the side of a gross observable lateral trunk list is not correlated with the side of symptoms.[18,61] Also, poor correlation between the side of movement limitation and the site of pain has been reported.[14,15] Such contradictory findings are not surprising since the location of a disc protrusion/extrusion relative to the nerve root will influence posture and movement. Similarly, our study did not reveal a link between laterality in pain and restricted movement in subjects who did not have evidence of disc lesions and radicular symptoms. This finding may suggest that some of our subjects could have been exhibiting function similar to those associated with early disc problems.

Obesity has been related to LBP.[62] In our study, the LBP group had significantly higher weight and body mass index than the controls. Excess weight has been noted as a potential correlate of back pain, although not all studies come to that conclusion.[63]

■ Conclusion

The results of our study support the use of normalized, rather than absolute, data for the accurate description of lumbopelvic asymmetry and biomechanical performance. Our results also support an association between subtle structural asymmetry and movement asymmetry. Although it is logical to conclude that the body's structure governs functional performance such as movement, it remains unknown whether a disturbance in normal function can lead to compensatory postures that may, in the long run, lead to pathoanatomic asymmetries. Given that our LBP group exhibited significantly more asymmetry of position and motion than our asymptomatic subjects, we speculate that such asymmetries in currently asymptomatic individuals may predispose them to LBP. It would thus be useful to know if such asymmetries could be early indicators of eventual discogenic LBP and subsequent radicular problems.

Our findings with respect to pelvic asymmetry and patterns of movement should provide clinicians with a broader understanding of the mechanisms involved in mechanical LBP. Although the system we used may be not applicable in a routine clinical setting, it could be used to test the accuracy of the more commonly used clinical tests of trunk mobility. Furthermore, our study provides objective methods for future studies to assess the effects of therapeutic interventions on pelvic skeletal asymmetries and LBP.

■ Key Points

- Asymmetry in lumbar lateral flexion and axial rotation effectively distinguishes between healthy individuals and patients with unilateral mechanical LBP.
- Asymmetry in lumbar movement is highly associated with pelvic asymmetry in both asymptomatic and LBP populations.
- We support the use of normalized, rather than absolute, data for the accurate description of lumbopelvic asymmetry and function.

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