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Differences in timing and magnitude of lumbopelvic rotation during active and passive knee extension in sitting position in people with and without low back pain: A cross-sectional study

Amin Behdarvandan[a], Mohammad Jafar Shaterzadeh-Yazdi[a,*], Hossein Negahban[b], Mohammad Mehravar[a]

[a] Musculoskeletal Rehabilitation Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[b] School of Paramedical Sciences, Mashhad University of Medical Sciences, Mashhad, Iran

ABSTRACT

Repetitive lumbopelvic rotation (LPR) during active limb movements has been indicated as a factor that contributes to low back pain (LBP). Prior studies suggest that people with LBP demonstrate greater and earlier LPR during limb movements in prone.

We examined timing and magnitude of LPR during sitting active knee extension in people with and without LBP. We also investigated differences of LPR during active and passive knee extension in LBP group. 38 men (mean age: 38.4)10.6) years) with chronic mechanical LBP and 38 matched healthy men (mean age: 36.6(8.4) years) were examined. Kinematic data were collected by motion capture system and analyzed using OpenSim software. The difference between the start time of knee extension and start time of LPR was calculated and was normalized to knee extension movement time. Maximum angular displacement for LPR was also calculated across time.

People with LBP demonstrated earlier LPR during knee extension than healthy subjects ($P < 0.01$). There was, however, no difference in maximum LPR between groups. LBP group also demonstrated greater and earlier LPR during active than during passive knee extension ($P < 0.01$).

Earlier LPR during limb movements in sitting may be related to LBP. Quadriceps muscle activity and inefficient trunk muscles activation may contribute to early LPR in LBP group. A greater understanding of the factors that may contribute to early LPR during daily activities can provide information to guide rehabilitation treatment for people with LBP.

1. Introduction

Low back pain (LBP) is a common medical condition in the society. The literature reports that up to 85% of population may experience LBP in their life (Andersson, 1999). Because of its great prevalence, LBP is ranked the leading cause of activity limitation and work absence in many countries and it imposes enormous economic burden on society (Kent & Keating, 2005; Steenstra, Verbeek, Heymans, & Bongers, 2005). These facts demonstrate a significant need to study different factors that may be related to LBP.

Repeated motions in the lumbopelvic region have been suggested to be associated with LBP (Scholtes, Gombatto, & Van Dillen, 2009) and a common belief is that many of lumbar spine problems are the result of cumulative microtrauma caused by movement patterns of lumbopelvic region (Sahrmann, 2002; Scholtes et al., 2009; Van Dillen et al., 2006). Several investigators have focused on relationship between various lumbopelvic motions and LBP. The interest in this relationship is based on the proposal that early and repetitive movement of lumbopelvic region during various activities of daily life is one of the main inducers of LBP (Sahrmann, 2002; Scholtes & Van Dillen, 2007). The early lumbopelvic motion means that lumbopelvic moves during the early range of limb and trunk functional movements. Many functional movements are performed in early and midranges of joint motions. It has been proposed that early lumbopelvic movement increases the frequency of lumbopelvic movement during functional activities (Scholtes et al., 2009).

* Corresponding author.
E-mail addresses: behdarvandan-a@ajums.ac.ir (A. Behdarvandan), shaterzadeh.pt@gmail.com (M.J. Shaterzadeh-Yazdi).

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Increased frequency of movement of lumbopelvic region during activities of daily life may contribute to increased stress on biological tissues, particularly if the lumbopelvic motion is always in the same direction (Adams, Bogduk, Burton, & The, 2002; Sahrmann, 2002). This causes injury and eventually LBP (Gombatto, Collins, Sahrmann, Engsberg, & Van Dillen, 2007; Mueller & Maluf, 2002; Sahrmann, 2002).

One of lumbopelvic motions that have been a focus of studies of people with LBP is axial rotation (Chimenti, Scholtes, & Van Dillen, 2013; Kim, Yoo, & Choi, 2013; Park et al., 2011; Scholtes, Norton, Lang, & Van Dillen, 2010; Van Dillen, Gombatto, Collins, Engsberg, & Sahrmann, 2007). Clinically, there are standardized active limb and trunk movement tests for assessment of lumbopelvic rotation (LPR) (Sahrmann, 2002; Van Dillen et al., 1998). Investigators have studied the effect of limb movement tests e.g. knee flexion and hip rotation on LPR. These studies indicate that people with LBP demonstrate earlier LPR during limb movement tests (Hoffman, Johnson, Zou, & Van Dillen, 2011; Scholtes et al., 2009, 2010).

Although prior studies have provided some insight into how LPR during limb movements relates to LBP, two issues have not been addressed adequately. First, no studies have examined the effect of voluntary limb movement tests that are performed in sitting position on lumbopelvic kinematics. The limb tests that have been studied are performed in prone position (Gombatto, Collins, Sahrmann, Engsberg, & Van Dillen, 2006; Hoffman et al., 2011; Park et al., 2011; Scholtes et al., 2009). Because many people spend long periods of time sitting while moving frequently their lower limbs, movement tests in sitting position are more functional than prone position movement tests. In people with LBP, controlling lumbopelvic motion during a functional movement is more important than during an isolated movement of hip rotation in prone. Therefore, studying kinematics of lumbopelvic region during a functional movement test in people with and without LBP may provide insight into the characteristics of lumbopelvic motions that may contribute to tissue injury and development of LBP during daily activities. Second, the factors that contribute to early LPR during active limb movements have not been studied in patients with LBP. Early LPR during limb movement could be the result of motor control factors, such as activation of trunk muscles or biomechanical factors such as tissue tension (Gombatto et al., 2006). Although performance of everyday tasks seldom requires people to use passive lower limb movements, it is important to study lumbopelvic motions during passive knee extension. During active and passive motion, we can examine various factors that may contribute to pattern of lumbopelvic motion in people with LBP. If tissue tension plays a role in early LPR during limb tests, then potentially active and passive forms of a limb test may display different patterns. In the studies, however, there is no data about pattern of LPR during passive limb movement tests. A better understanding of possible factor that contributes to early LPR during limb tests could assist in better directing examination and treatment of people with LBP.

Therefore, the purposes of the current study were to (1) examine differences in timing and magnitude of LPR during knee extension in sitting between people with and without LBP, and (2) identify potential differences of LPR during active and passive knee extension in people with LBP. Based on the prior data, we hypothesized that people with LBP would demonstrate greater and earlier LPR compared to people without LBP. We also hypothesized that compared to passive knee extension; there would be greater and earlier LPR during active knee extension in people with LBP.

2. Method

2.1. Setting and participants

For this cross-sectional observational study, two groups of participants were recruited: people without LBP (Healthy) and people with a history of LBP. Nonprobability, convenience sampling method was used to select available subjects who meet study criteria. The healthy group subjects were recruited from the university campus, family members and friends. People with LBP were invited to participate from two local physical therapy outpatient clinics. Men were only chosen to participate in the study because movement patterns of men and women during limb tests were different. Based on the results of previous studies, men with LBP demonstrated earlier LPR during limb movements compared to women (Gombatto et al., 2006; Hodges & Moseley, 2003). Men, also, were more likely to have symptoms during limb tests (Gombatto et al., 2006). Therefore, more men than women demonstrate lumbopelvic motions that are related to LBP. The healthy group included 38 men (mean age: 36.6(8.4) years) without a history of LBP over the past year. The LBP group consisted of 38 men (mean age: 38.4(10.6) years) who reported a history of chronic mechanical LBP (eg, degenerative joint disease, degenerative disc disease, spinal stenosis) (Chien & Bajwa, 2008) for at least 6 months and were not in an acute flare-up of LBP during testing (Von Korff, 1994). All subjects with LBP associated their symptoms with their daily activities. Based on movement system impairments (MSI) model for LBP (Sahrmann, 2002), people with LBP that were classified into Rotation-Extension, Rotation-Flexion or Rotation subgroups were included in study. All subjects of LBP group reported an increase in their symptoms during or after activities of daily life. Subjects were excluded if they reported any of the following: history of spinal or lower extremity surgery or fracture, spinal deformity diagnosed by physician, presence of hip or knee problem, body mass index (BMI) greater than 30, systemic inflammatory condition and neurological disease.

Because factors such as age and BMI contribute to passive tissue characteristics, subjects of both groups were matched on these variables (Gombatto et al., 2006, 2008). Subject characteristics of both groups are presented in Table1.

Prior to participation in the study all subjects were provided details of the testing, and they read and signed an informed consent form. This study was approved by Scientific Ethical Committee of Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.

2.2. Examination items

A physical therapist examined each subject with LBP and classified them into the subgroups according to standardized clinical

Table 1
Demographic and functional characteristics of LBP and healthy groups.

	LBP group (n = 38) Mean (SD)	Healthy group (n = 38) Mean (SD)	*p* Value
Age (yr)	38.4 (10.6)	36.6 (8.4)	0.413
Body mass index (kg/m^2)	26.9 (2.1)	26.6 (3.4)	0.735
Pain in past week (0–10)	4.2 (2.2)	N/A	N/A
Duration of LBP (yr)	2.5 (1.4)	N/A	N/A
Baecke activity score (3–15)	7.16 (1.84)	7.21 (2.08)	0.906
ODI (0–100%)	14.21 (6.04)	N/A	N/A

SD: Standard Deviation, N/A: Not Applicable.

examinations and rules for classification based on MSI model (Harris-Hayes & Vandillen, 2009) (Maluf, Sahrmann, & Van Dillen, 2000). The examiner practiced the standardized examinations for 3 years before beginning the study. Interrater reliability of MSI examinations for patients with chronic LBP and ability of examination items to classify individual's LBP has been found to be acceptable (Trudelle-Jackson, Sarvaiya-Shah, & Wang, 2008). In reliability studies for MSI examinations for patients with LBP the reported kappa values were 0.61–0.81 (Harris-Hayes, Van Dillen, & Sahrmann, 2005; Henry, Van Dillen, Trombley, Dee, & Bunn, 2013; Trudelle-Jackson et al., 2008; Van Dillen et al., 1998) and percentage of agreement were 75–87.4% (Harris-Hayes et al., 2005; Henry et al., 2013; Trudelle-Jackson et al., 2008).

The examinations consisted of primary and secondary posture and movement test items (Maluf et al., 2000; Van Dillen et al., 1998). Symptoms of LBP were monitored during primary tests. The secondary test was performed for each primary test that was symptom-provocating. Lumbar spine was positioned in neutral alignment during secondary tests and symptoms were monitored again (Van Dillen, Sahrmann, Norton, & Caldwell, 2003). In this study 20 subjects were classified into Rotation-Extension subgroup, 13 subjects into Rotation-Flexion subgroup and 5 subjects into Rotation subgroup.

Before examination, each subject of LBP group completed self report measures including: A demographic and LBP history questionnaire, Iranian version of Oswestry Disability Index (Mousavi, Parnianpour, Mehdian, Montazeri, & Moboni, 2006), Persian version of Baecke habitual physical activity questionnaire (Sadeghisani, Manshadi, Azimi, & Montazeri, 2016) and Visual Analogue Scale to rate average pain over the past 7 days (Deyo et al., 1998). A 1-week time frame is suggested because it is long enough for patients to experience meaningful changes of symptoms. It is, also, short enough to remember the changes and memory is not likely to be a problem for patients (Deyo et al., 1998).

Subject characteristics for people with LBP are presented in Table1.

2.3. Kinematic data collection

Kinematic data were collected using 7-camera, 3-dimensional, Qualisys motion capture system (Qualisys Inc., Gothenburg, Sweden) and sampling rate of 100 Hz. 19 Retro-reflective markers placed on right and left lateral malleolus, lateral knee joint line, upper one third of lower legs and thighs, lower one third of lower legs and thighs, greater trochanters, bilateral anterior superior iliac spine (ASIS), bilateral posterior superior iliac spine (PSIS) and spinous process of second sacral vertebra (S2). Kinematic coordinate of markers were gap filled using a spline smoothing algorithm and then filtered using a zero lag, second order, Butterworth low pass filter with a cutoff frequency of 10 Hz. A custom written Matlab (version R2015a, The Mathworks Inc, Natick, Massachusetts) program was used to filter the row kinematic data.

For both active and passive knee extension tests, subjects were instructed to sit on the edge of an examination table. Every subject was adjusted so that hip and knee angles were 90°, feet were not in touch with floor, lumbar region was neutral and arms were crossed on chest (Fig. 1).

For active trials, participants were asked to actively extend each knee separately as much as possible at a self-selected speed and then return to starting position. Each trial consisted of one repetition and the allotted time for each movement was 10 s. Before active trial began, the procedure was explained to subjects. Because it might increase LBP symptoms and have influences on pattern of LPR, we had no active practice before beginning the tests.

After completion of active trials, right and left passive knee extension were separately performed by the same examiner that conducted standardized examinations. While the subject was sitting on the edge of examination table, the distal portion of one lower leg was grasped and moved passively by the examiner in the direction of knee extension. Each passive movement consisted of one repetition. For each subject, passive knee extension was performed synchronized with pre-recorded active knee extension of the same side that was shown for the examiner on a 40-inch screen. The examiner tried to move the lower leg with the same speed as active trial. Knee extension range of motion and mean angular velocities during active and passive trials were calculated to be sure that both trials have been performed with the same range of motion and velocity. The data for these variables are presented in Table2. Subjects were instructed to relax quadriceps muscle during passive knee extension. To ensure that subjects relaxed the muscle, myofeedback (Myomed 432, Enraf-Nonius, Rotterdam, Netherlands) was used during passive trial. Auditory and visual feedbacks from quadriceps muscle activity were given to subjects by myofeedback device. During passive movement, muscle contraction was also manually detected by examiner and verbal feedback was given to subject. Before passive trial began, the procedure was practiced. During practices, the examiner watched pre-recorded active knee extension of participant. After that he tried to move the lower leg of

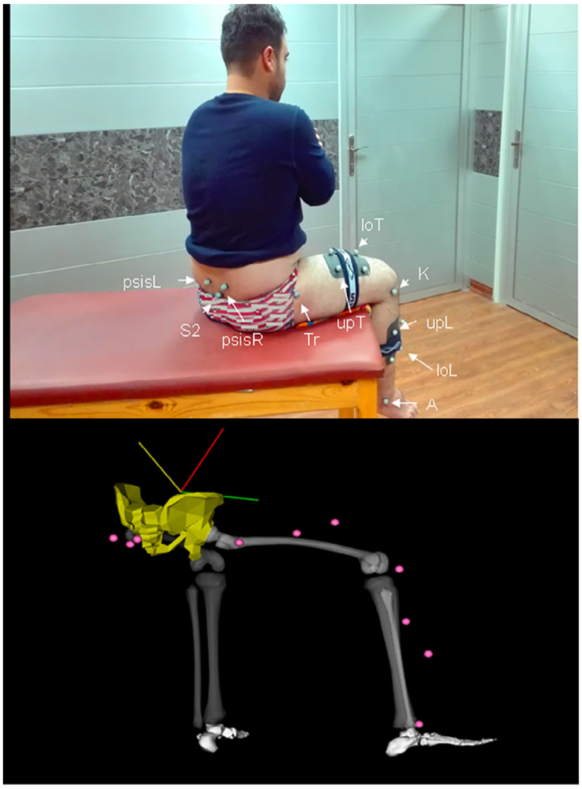

Fig. 1. Representation of markers and pelvis segment axes in the initial position of knee extension in sitting. Marker key: PsisL, left posterior superior iliac spine; PsisR, right posterior superior iliac spine; S2, spinous process of second sacral vertebra; Tr, greater trochanter; upT, upper one third of thigh; loT, lower one third of thighs; K, lateral knee joint line; upL, upper one third of lower leg; loL, lower one third of lower leg; A, lateral malleolus.

Table 2
Means (SD) and statistical values for knee extension velocity and ROM for people with and people without LBP.

Variables		Group				*p* Value
		LBP		Healthy		
		Active	Passive	Active	Passive	
Knee Extension RoM (deg)	Rt	71.18 (6.46)	70.32 (4.64)			0.220
	Lt	69.93 (6.36)	68.70 (6.16)			0.155
	Rt			70.51 (2.68)	71.71 (7.04)	0.314
	Lt			74.82 (8.30)	72.36 (7.05)	0.104
Knee Extension Velocity (deg/sec)	Rt	54.59 (14.14)	52.28 (10.05)			0.315
	Lt	54.30 (12.67)	51.87 (11.85)			0.320
	Rt			54.23 (14.46)	50.85 (12.46)	0.168
	Lt			54.56 (13.28)	56.48 (8.47)	0.217

RoM: Range of Motion; Rt: Right; Lt: Left.

participant synchronized with active knee extension of the same side at least 2 or 3 times. While the lower leg was moved, pre-recorded active knee extension of the same side was shown for the examiner on screen.

2.4. Kinematic measurements

Kinematic data were processed by OpenSim software (Stanford University, Palo Alto, CA) (Seth, Sherman, Reinbolt, & Delp, 2011) to extract joint angles. The segments of scaled model were pelvis, thighs and lower legs. ASIS, PSIS and S2 markers were used to define pelvis segment, greater trochanter, knee and thigh markers were used to define thigh segment and lateral malleolus, knee and lower leg markers were used to define lower leg segment. Consistent with prior studies, motion of pelvis segment was used to index LPR (Gombatto et al., 2006; Scholtes et al., 2009; Van Dillen et al., 2007).

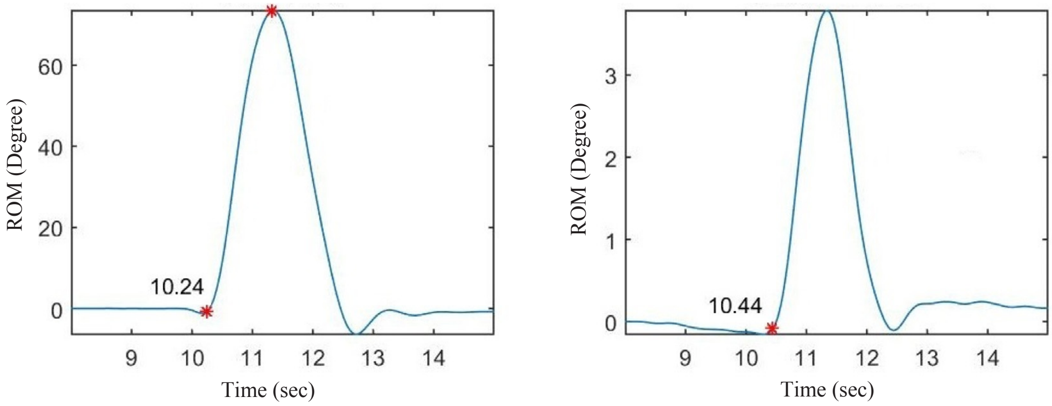

Fig. 2. Left knee extension (left) and LPR (right) angle profile. Start time of knee extension is 10.24 s and start time of LPR for the same subject is 10.44 s.

Angular velocity and displacement for LPR and knee extension were calculated across time. Each movement's angular velocity was plotted against the time. Knee extension and LPR initiation and termination were identified using threshold criteria of angular velocity. The initiation of knee extension was identified when angular velocity of knee exceeded 5% of its maximum (Gombatto et al., 2006). The termination of knee extension was identified when knee angular velocity came back below 5% of its maximum. The initiation of LPR was identified when angular velocity of pelvis segment rotation exceeded 15% of its maximum (Gombatto et al., 2006) (Fig. 2). Because lumbopelvic region, in some of participants, had small range of motion without a clear bell-shaped velocity profile, we used an iterative algorithm to detect movement's initiation and termination.

A relative time index (RTI) was calculated to assess the difference between the start time of knee extension and start time of LPR. To calculate RTI, the difference between start times was normalized to the knee extension movement time (Gombatto et al., 2006). A custom written Matlab program was used to extract RTI.

Intrarater reliability of knee extension and maximum LPR measures was assessed in a sample of 11 people with LBP. Intraclass correlation coefficient (ICC 2,1) (Eliasziw, Young, Woodbury, & Fryday-Field, 1994) and 95% confidence intervals were calculated to index reliability. The values of reliability coefficient are determined as follows (Eliasziw et al., 1994): slight (0.04.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00). The values for knee extension were found substantial to perfect and for LPR were perfect (Table3).

2.5. Statistical analysis

IBM SPSS Statistics (Version 20, IBM Corporation, Armonk, NY) was used to perform statistical analyses. Descriptive statistics (mean and standard deviation) were calculated for subject characteristics and self-report measures. Independent t-tests were used to test for differences between LBP and healthy groups in age, BMI and Baecke activity score. Paired-samples t-tests were used to test for differences between active and passive knee extension range of motion and mean velocities in LBP and healthy groups. Normal distributions of data were tested using Kolmogorov-Smirnov test. If the Kolmogorov-Smirnov test was significant ($p < 0.05$), then the data were considered non-normal and they were log transformed before statistical analysis. Distribution of maximum LPR during active knee extension and relative time index during passive knee extension in LBP group and maximum LPR during active and passive knee extension and relative time index during passive knee extension in healthy group were not normal. The log transformation resulted in a normal distribution for all dependent variables. Statistical analysis were carried out with and without the log transformation on the maximum LPR and RTI measurements, but yielded similar results. Thus, for ease of interpretation, the

Table 3
ICC and 95% CI for knee extension and maximum LPR.

Variable	ICC(2,1)	(95% CI)
Active Right KE ROM	0.78	(0.394–0.940)
Active Left KE ROM	0.73	(0.295–0.921)
Passive Right KE ROM	0.86	(0.598–0.964)
Passive Left KE ROM	0.81	(0.441–0.941)
Active Right LPR	0.85	(0.540–0.957)
Active Left LPR	0.86	(0.565–0.959)
Passive Right LPR	0.81	(0.462–0.944)
Passive Left LPR	0.89	(0.643–0.969)

ICC: Intraclass Correlation Coefficient, CI: Confidence Interval.
KE: Knee extension, LPR: Maximum lumbopelvic rotation.

Table 4
Means (SD) and statistical values for lumbopelvic rotation, relative time index for people with and people without LBP.

Variables	Group				*p* Value*
	LBP		Healthy		
	Active	Passive	Active	Passive	
Maximal Lumbopelvic Rotation (deg)	**2.92 (1.39)**	**1.89 (0.77)**	**2.90 (1.57)**	**1.89 (0.97)**	0.97, between groups **< 0.01, between conditions** 0.94, group × condition
Relative Time Index	**0.15 (0.24)**	**0.37 (0.14)**	**0.36 (0.33)**	**0.48 (0.21)**	**< 0.01, between groups** **< 0.01, between conditions** 0.12, group × condition

* Statistics values in bold face indicate a significant effect.

untransformed variables are presented in this study. 2-way analysis of variance (ANOVA) tests were conducted to analyze main and interaction effect of group (LBP, Healthy) and condition (active, passive) on maximum LPR and RTI. Because there were no significant differences between right and left trials for any of dependent variables, data for right and left trials were averaged in LBP and healthy groups (Chimenti et al., 2013; Scholtes et al., 2009). Alpha was set at $p \leq 0.05$.

3. Results

3.1. Subject characteristics and self-report data

People with and without LBP were not statistically different with regard to age, BMI and Baecke activity score ($P > 0.05$ for all comparisons). (Table1)

3.2. Kinematic data

We compared people with and without LBP with regard to maximum LPR angles and RTI. The maximum LPR angles and RTI for both groups, during active and passive knee extension, are provided in Table4. Knee extension range of motion and angular velocities during active and passive trials also are presented in Table2.

For maximum LPR (Table4), there were no interaction of group × condition and no significant differences between groups. There were, however, significant differences between active and passive conditions for maximum LPR angles. Both LBP and healthy subjects decreased maximal LPR range of motion from active to passive knee extension trial.

For RTI (Table4), there was no interaction of group × condition. There were, however, significant differences between groups and between active and passive conditions. LBP group demonstrated less RTI than healthy group both during active and passive trials and subjects of both groups increased RTI from active to passive knee extension trials.

There were no significant differences in knee extension ranges and velocities between active and passive trials in both groups (Table2).

4. Discussion

The purpose of this study was to examine timing and maximum range of LPR during knee extension in sitting. We compared subjects who were assigned to healthy and LBP groups. The results of current study support the hypothesis that people in LBP group show earlier LPR during knee extension when compared with people in healthy group. There was, however, no difference in maximum range of LPR between groups. The findings of current study, on the other hand, demonstrated that movement patterns of active and passive trials in both groups were different and they displayed greater and earlier LP rotation during active knee extension than passive knee extension.

There are studies that have examined knee extension test only within the context of a clinical examination (Van Dillen et al., 2003b, 2001, 1998). Scholtes and Van Dillen identified LPR during knee extension with clinically-based measures and reported that people with LBP demonstrated early LPR during knee extension in sitting (Scholtes et al., 2009). Their judgment was made by trained examiners. Rotations are so small that accurate visual detection seems unlikely. To our knowledge, the current study is the first to examine the LPR during knee extension in sitting through kinematic analysis.

Investigators have previously identified greater and earlier LPR during limb movement tests in prone position in people with LBP (Gombatto et al., 2006; Hoffman et al., 2011; Scholtes et al., 2009). Movement tests in sitting position, however, are more functional than prone position limb movement tests. Thus, earlier LPR during knee extension in people with LBP is important because it may represent the movement pattern they use frequently in functional activities. Many of voluntary movements are performed in early ranges of joint motions. Early LPR increases the frequency of the movement during activities of daily life. Thus, repetitive rotation of lumbopelvic region during performed activities in sitting may contribute to tissue injury and eventually LBP (Sahrmann, 2002). Prior studies, also, demonstrated that altering the lumbopelvic motion demonstrated during limb movements in people with LBP improved symptoms (Van Dillen et al., 2003a, 2009). Thus, the early LPR identified during knee extension may be important to consider in treatment strategies.

Early LPR during active knee extension in people with LBP may be the result of control or biomechanical factors (Gombatto et al., 2006). Prior studies do not directly address the underlying factors that may contribute to pattern of LPR during limb movement tests (Gombatto et al., 2006; Hoffman et al., 2011; Scholtes et al., 2009). Scholtes et al suggested that because there is no biomechanical explanation, the early LPR during prone active knee flexion in people with LBP may be the result of motor control factors (Scholtes et al., 2009). The current study differs from these studies in that both active and passive knee extension were examined. In the absence of interaction between group and condition, different RTI in LBP and control subjects should be attributed to biomechanical factors. In both groups, during active knee extension, quadriceps muscle contracts to move the lower leg. Such a muscular activity does not exist during passive knee extension. Quadriceps activation could cause tension on passive tissues, which could in turn pull on the pelvis. Moreover, the rectus femoris attaches to the pelvis and thus directly pulls on the pelvis and lumbopelvic region. Thereby we consider biomechanical factors as an underlying factor for a rotational path of least resistance in lumbopelvic region of people with LBP.

Prior to active limb movement, trunk muscles contract to stabilize the spine against perturbations produced by the limb movement (Hodges & Richardson, 1997). This control mechanism of spine and activity of superficial and deep trunk muscles is altered in people with LBP (Hodges & Moseley, 2003; Hodges and Richardson, 1997, 1999; Hodges, Moseley, Gabrielsson, & Gandevia, 2003; Jacobs, Henry, & Nagle, 2009). The earlier LPR in LBP group, compared to healthy group, suggests that the inefficient control mechanism of trunk muscles activation is not able to prevent early LPR in people with LBP.

There were no differences in maximum LPR between LBP and healthy group. This is in contrast with previous studies examining prone knee flexion and hip rotation (Gombatto et al., 2006; Hoffman et al., 2011; Scholtes et al., 2009). Data from these studies have shown greater LPR during limb movement tests in prone position in people with LBP. Sitting balance, however, has been shown to be impaired in people with LBP (Radebold, Cholewicki, Polzhofer, & Greene, 2001) and altered active control mechanisms such as hyperactivity of trunk muscles in people with LBP serves to control sitting balance and limit lumbopelvic movement (Hodges & Moseley, 2003; Hodges & Richardson, 1999).

Compared to passive knee extension, greater and earlier LPR during active knee extension, provide additional support for the proposal that quadriceps activation may play a role in early LPR in people with LBP. If quadriceps activation were not the cause of greater and earlier LPR, then there would be no differences in LPR between active and passive trials. Future research may be needed to indicate if exercises that improve lumbopelvic stability may alter and normalize the earlier LPR during active knee extension in sitting in people with LBP.

There are some limitations in the current study. First, because sex could influence the variables reported in the study, men were the only subjects that were recruited for the study. Future research examining magnitude and timing of LPR during knee extension in women with LBP is warranted. Second, Small sample sizes (N = 38, each group) and minimal pain and disability levels of LBP group may limit the generalizability of the findings of current study. Patterns of LPR may be influenced by acute pain. Therefore, patients that were not in acute fare-up of LBP and had relatively low disability level (14.2% Oswestry Disability Index) were included in the study. Future studies could explore pattern of LPR during limb movements in sitting in people with LBP who demonstrate a variety of pain and disability levels. The small sample size was, also, a limitation. However, the findings in this sample are consistent with previous studies, lending support to their validity. Finally, with the use of surface markers, skin-motion artifact is common (Cappozzo, Catani, Leardini, Benedetti, & Croce, 1996). The impact of skin artifact on kinematic measures has not been yet explored (Mazzone, Wood, & Gombatto, 2016).

Despite these limitations, we believe the results of current study are important. A greater understanding of the factors that may contribute to motions of lumbopelvic region during daily activities in people with LBP can provide information to guide rehabilitation treatment for LBP. Findings of our study about pattern of LPR in people with Rotation-Extension, Rotation-Flexion and Rotation subgroups of LBP supports the need for further examination of whether active modifications of lumbopelvic motions can be effective for alleviating symptoms in these subgroups during daily activities.

5. Conclusion

Repetitive lumbopelvic motion is an important factor that may lead to LBP. In this study, compared to healthy subjects, people with LBP demonstrated earlier LPR during limb movements in sitting. The earlier LPR may increases the frequency of the lumbopelvic motion and may contribute to development of LBP. Findings from current study also suggest that quadriceps muscle activity and inefficient trunk muscles activation may contribute to earlier LPR identified in LBP group. Thus, active control factors may be important for clinicians to consider when limb movements provocating symptoms of LBP.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.humov.2019.02.012.

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