RESEARCH ARTICLE

The Ratio of Lumbar to Hip Motion during the Trunk Flexion in Patients with Mechanical Chronic Low Back Pain According to O'Sullivan Classification System: A Cross-sectional Study

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Received: 11 April 2018 *Accepted: 21 June 2018*

Abstract

Background: Static and dynamic postures of lumbopelvic in low back pain (LBP) are considered as two important aspects of clinical assessment and management of LBP. Thus, the focus of the current study was to compare the posture and compensatory strategy of hip and lumbar region during trunk flexion between LBP subgroupsand health subjects. LBP cases are subdivided into active extension pattern (AEP) and flexion pattern (FP) based on O'Sullivan's classification system (OCS).

Methods: This work was a cross-sectional study involving 72 men, 21 low back pain patients with FP and 31 low back pain patients with AEP and 20 healthy groups. Lumbar and hip angles during trunk flexion were measured by a 3D motion analysis system in neutral standing posture and end-range of trunk flexion. The participants were asked to full bend without any flexion of the knees. The bending speed was preferential. Hip and lumbar ranges of motion were divided into four quartiles (Q). The quartiles were compared between groups. Data analysis was performed using one-way analysis of variance (ANOVA) and independent t-test.

Results: There was no statistically significant difference in lumbar lordosis in standing and full trunk flexion positions between the healthy groups and heterogeneous LBP groups. In addition, there was not any statistically significant difference between the healthy group and the homogenous LBP group (FP and AEP). Moreover, no statistically significant difference was observed in hip angles during standing between the healthy group and the heterogeneous LBP group, and between the healthy group and the homogenous LBP group (FP and AEP). In full trunk flexion position, there was statistically significant difference in hip angles between the healthy group and the heterogeneous LBP group (P=0.026). In this position, the difference in hip angles between the healthy group and FP group was statistically significant (*P<0.05*). In the second Q, there was no significant difference between the healthy group and the heterogeneous LBP group (*P=0.062*), however, there was a significant difference between FP group and the healthy group in the fourth Q of the total hip range of motion. There was no statistically significant difference between the healthy group and the heterogeneous LBP group (*P=0.054*) but there was a difference between FP group and the healthy group. Lumbar/hip motion ratio (L/H ratio) was different between and within the subgroups in the second Q.

Conclusion: This study supported the subgrouping of LBP and showed that the difference between subgroups could be determined effectively through subdividing the total range of lumbar and hip motions into smaller portions. It is possible that the neuromuscular system selects different strategies to compensate and prevent further injury of the chain components (muscle, joint, nerve and etc.).

Level of evidence: IV

Keywords: Classification, Forward flexion, Kinematics, Low back pain, Lumbar spine, Posture

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THE ONLINE VERSION OF THIS ARTICLE
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Introduction

LBP is one of the most frequent and costly musculoskeletal pain syndromes worldwide. About 85% of LBP patients have no obvious pathoanatomic/radiologic defects that are classified as non-specific chronic low back pain (NSCLBP) (1, 2). This may lead to poor diagnose of LBP with subsequent effects on the management of NSCLBP. There is sufficient evidence showing the current managements of NSCLBP are not superior to each other, and their long-term effects are limited. One possible reason of poor or misdiagnosis is associated with the study of NSCLBP population in the form of heterogeneous varieties. The "wash-out effect" may occur in this condition. In the "wash-out effect", the findings from one subgroup of patients are eliminated by the opposite findings from another subgroup (1). Another possible reason for these failures is the lack of a multidimensional classification system (MDCS) (3).

It has been suggested that the NSCLBP population should be categorized into homogeneous subgroups (4). O'Sullivan has declared a new MDCS for LBP that is called 'classification-based cognitive functional therapy' (CBCFT) (3). In this model, analysis of spinal postures and movements is an important part. Based on their reports, these spinal postures and movements are easing and aggravating factors of LBP (2, 5).

However, there is not enough formal evidence about these clinical assessments (2, 5). Flexion pattern (FP) and active extension pattern (AEP) are the two most common clinical LBP patterns within the 'maladaptive motor control impairment' subgroup in this MDCS (2, 5). Flexion of the spine is a common movement in daily activities that is the most common mechanical cause of lumbar injury (6, 7). Knowledge of biomechanics and clinical implications and their compensatory strategy of lumbar and hip posture and coordination (lumbopelvic rhythm) during trunk forward flexion could have an impact on the management of LBP (2, 6, 8). The compensatory strategies of lumbar region and hip may be performed in the form of increase or decrease of ROM or the alteration the posture of lumbar region (lordosis, kyphosis or flat) and pelvis (anterior or posterior pelvic tilt). These compensatory strategies of lumbar region and hip maybe explained by relative-flexibility theory of Sahrmann (9, 10). In this classification system, spinal flexion is an easing and aggravating factor of AEP and FP, respectively (2). Thus, in this study forward flexion was selected for testing the patients.

The aims of this study were to investigate and compare the lumbar and hip postures (static) and movements (dynamic) in healthy group, FP, AEP and pooled NSCLBP group during trunk flexion. We hypothesized that the subgroups of LBP would have different ratio of lumbar to hip motion during trunk flexion. In addition, the subgroups would demonstrate the different lumbar and pelvic postures in standing and full trunk flexion position.

Materials and Methods

Study design

This cross-sectional study was designed to compare differences in the lumbar and hip posture (static) and movement (dynamic) during trunk flexion when standing in the healthy group with pooled NSCLBP group. Also, subjects with NSCLBP were divided into FP and AEP subgroups.

Participants

Our study was designed based on 72 men involving 21 LBP with FP, 31 LBP with AEP and 20 healthy subjects. The subjects with NSCLBP were not significantly different from the healthy group concerning height, age or body mass index and there were no significant differences in age, weight, height, and body mass index among the subgroups [Table 1]. Exclusion criteria for LBP patients and healthy subjects (by clinical examination and interview) included radicular pain, neurological signs, serious spinal complications (e.g. tumor or infection), previous spinal surgery, cardiovascular disorders, uncorrected vision problems, severe musculoskeletal deformity, professional sport, restricted trunk flexion task in the standing position or other disorders that could interfere with testing. Moreover, healthy group had no LBP during the last 12 months that required medication or consultation with a healthy professional and/or days off work. Inclusion criteria for LBP included continuous or recurrent symptoms for 3 months or more, Oswestry score less than 15%, absence of "red flags" (such as cauda equine syndrome or inflammatory disease) and dominant "yellow flags" (like beliefs and emotions),

Table 1. General characteristics (Mean ± SD) of the subjects

Variable	FP	AEP	Heterogeneous LBP	Normal group	P$^{\Delta}$	P*
Height	175.27 ± 7.15	173.69 ±7.02	174.49 ± 7.03	175.52 ± 5.1	0.655	0.552
Weight	78.85 ± 11.22	100.23 ±118.65	91.6 ± 91.88	8.72 ± 78.05	0.511	0.514
Age	34.71 ± 8.05	32.45 ± 9.97	33.37 ± 9.23	31.75 ± 7.43	0.521	0.478
BMI	25.61 ± 2.92	32.66 ± 36.73	29.81 ± 28.45	25.34 ± 2.63	0.467	0.467

Abbreviations: BMI, Body mass index; FP, Flexion pattern low back pain group; AEP, Active extension pattern low back pain group

$^{\Delta}$: Comparison between subgroups (FP and AEP) and normal subjects *: Comparison between heterogeneous LBP and normal subjects mechanical provocation of pain, pain in the area from T12 to gluteal folds. Patients with clinical signs of motor control impairment were subgrouped based on the classification system proposed by O'Sullivan (11, 12). NS-CLBP subclassification was done by a clinician (musculoskeletal physiotherapist). He was familiar with O'Sullivan classification system and had a certificate. All LBP cases were included in the NS-CLBP (pooled) group. The clinical features of these subgroups are shown in Table 2. The subjects were provided details about the experiment, and they provided written informed consent before their participation in our study.

Instrumentations

For recording the lumbopelvic posture and movement parameters, a 3D motion analysis system (a 6-camera motion capture system, Qualisys AB, Sweden) consisting of six cameras and its related software (Qualisys Track Manager) was used. A total of 12 retro-reflective markers were attached to the participant's spine and lower limbs by double-sided adhesive tape in the following arrangement:

1- Three markers on the spine at the C7, L1, L5,

2- Three markers on the pelvis; one marker attached to the S2 and two markers attached to the bilateral anterior superior iliac spines,

3- Six markers over the landmarks of lower limbs (bilaterally), the greater trochanter, lateral condyle of femur and lateral malleoli.

The kinematic parameters during the test were studied by angular displacements of the lumbar and hip joint during the forward flexion periods (13). The parameters were as follows: sagittal lumbar and hip angle, percentage of contribution of lumbar region and hip and lastly, lumbar/hip motion ratios (L/H ratio). Sagittal lumbar angle was calculated as the angle composed of a straight line connecting the mid-point of L5 marker and the mid-point of the L1 marker and a straight line connecting the mid-point of S2 and mid-point of L5 marker in the sagittal plane [Figure 1]. The angle of 180 was defined as a flat lumbar posture when the two lines were collinear. Hip angle was measured as the angle between the straight line attaching the mid-point of S2 and the mid-point of L5 markers and the straight line attaching the right lateral knee and the right greater trochanter markers in the sagittal plane for forward bending [Figure 1]. Degree of 180 was considered once these lines were parallel. The sampling rate was 100 Hz. The recorded kinematic data were initially filtered using a fourth order dual pass Butterworth Filter with a cut-off frequency of 2.0 Hz. Given that the subjects performed the test at self-selected speeds, an individual filtering frequency was applied according to their own movement times. Raw data were filtered at subject-specific frequencies with the following equation: 1/[0.15*(movement time)] (14). To get the ROM of lumbar and hip joints, the joint angle in the normal standing position of the joints was deducted from the angle of the joints at the end-range of trunk flexion. Lumbar ROM was divided into four quartiles (Q) with respect to time: quartile 1 (0-25% of the total time), quartile 2 (25-50% of the total time), quartile 3 (50-75% of the total time) and quartile 4 (75-100% of the total time) (15). The ROM for each quartile was obtained by subtracting the lumbar angles at the end and the beginning of each quartile. The percentage

Table 2. The clinical features of low back pain subgroups

Clinical features of FP group	Clinical features of AEP group
Aggravating/Easing Factors: Repeated movements and sustained postures (functional activities) involving flexion of the lumbar spine (e.g. slouched sit and squatting, cycling, forward bending), sitting without back support. Spinal extension postures/activities that increase lumbar lordosis relieves pain, (e.g. standing, sitting with a lumbar roll, walking)	**Aggravating/Easing factors**: Movements and postures (functional tasks) associated with the key feature hyper-extension of lumbar (hyper-lordotic sitting and standing, forward bending, carrying out overhead activities, fast walking, running and swimming) increase symptoms. Spinal flexion postures/activities (e.g. crook lying, slouched sitting) relieves pain
Postural and movement disorders: Challenge accepting or holding neutral lordotic postures with a tendency to loss of motor control into flex lower lumbar spine and a compensatory upper lumbar lordosis and lower thoracic and incremented tone in the thoracic erector spinae muscles, Loss of segmental lordosis at involved Segment without spinal mobility disorder in daily routine activities, such as sit-to-stand, squatting and gait, trunk flexion movements commonly demonstrate a trend of an early 'loss of lower lumbar lordosis' (lumbar curve reversal). Decreased muscle tone in SLM evaluated by manual palpation, The pelvis is often positioned in the posterior pelvic tilt.	**Postural and movement disorders:** Excessive segmental lordosis at symptomatic level, challenge accepting or holding neutral lordotic postures with an inclination on setting their lumbars under hyperextension, expanded muscle tone done SLM evaluated by manual palpation. During many of the daily routine activities, such as sit to stand, squatting and trunk flexion, the affected segment tends to have excessive lordosis. Increase in the flexion of the hip joints can be seen and the lumbar spine has lost its lordosis (after the mid-range) with delay or no lumbar kyphosis, during forward bending observed. During the return to the standing position from the bowed forward direction, the early hyper-lordosis of the lumbar at the affected segments is visible. Inability/absence of motor control with beginning a posterior pelvic rotation.

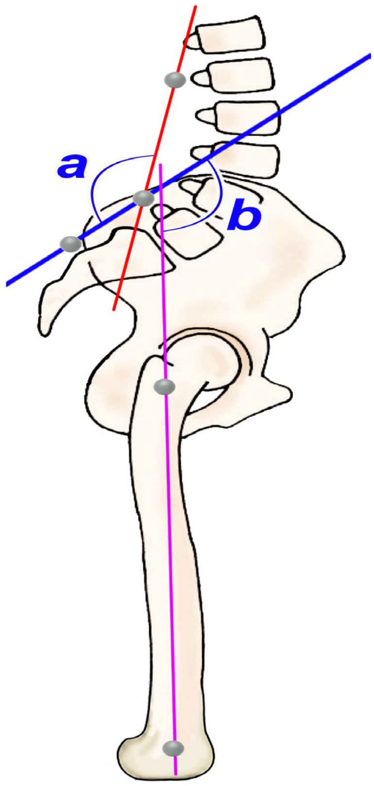

Figure 1. Hip and lumbar angles. (a) lumbar angle. (b) hip angle.

of contribution of each quartile of lumbar ROM to the overall lumbar flexion ROM was defined as ROM of each quartile divided by the total ROM of lumbar region multiplied by 100. This process was repeated for hip joints. To calculate the L/H ratio, lumbar and hip ROM in each quartile was calculated initially, as mentioned above. Then, the ratio of lumbar to hip motion was calculated by dividing each quartile of lumbar region by the same quartile of the hip in the sagittal plane (8). MATLAB software R2014a (8.3.0.532) was used for calculating mentioned values.

Experimental design and procedure

The subjects stood with their parallel feet pelvis-width apart. Also, they were barefoot and wore a tight-fitting elastic spandex. Participants wore no shirt and pants. Before subjects performed the test the camera system was calibrated with wand calibration method. The L-shaped reference structure was placed in the measurement volume and calibration wand was moved in the measurement volume in this method. The calibration time was set longer than 10s. The calibration software ensured accuracy by providing an estimate of system measurement error (16). During the trunk flexion, knees were straight, and bending speed was preferential. Their arms were hanged freely along the body and the weight was equally distributed between both feet on the testing floor. Our participants were given one or two practice trials as the movement task for dynamic capture. Moreover, the subjects were asked to stand in neutral position at least for 3 seconds (standing phase), and then they started to flex forward with the examiner's order while their arm were hanging freely. The subjects were instructed to hold the end-flexed position for 3 seconds (full flexion phase). Vertical movement of the marker on the seventh cervical vertebrae (C7) was plotted by QTM (Qualisys Track Manager) software for precise selection of the dynamic phase of trunk flexion. Subsequently, through plot zooming, the point which vertical displacement of the marker increased continuously (beginning of movement) was selected as the start point of the test. End point of the test was determined once the marker height was decreased and arrived at the lowest height. For higher precision, eye observational comparison was made with the subject's movement.

The marker of C7 was selected owing to its clear vertical displacement, and the cameras detected it completely during the trunk flexion. The subjects performed three trials after completing the practice. The mean of the three trials was utilized for data analysis. Reliability of the motion analysis system for tracking the three-dimensional marker positions was studied by Kejonen et al. who reported variations in the intra-class correlation coefficients (ICC) values to range from 0.44 to 0.70 in the lateral direction, from 0.33 to 0.86 in the anterior-posterior direction, and from 0.27 to 0.79 in the vertical direction (17).

Statistical analysis

All analyses were performed in the sagittal plane. Frontal plane was ignored since the sagittal curvature of the lumbar region is important in subgrouping of FP and AEP. Data were analyzed for the lumbar curvature angle. Figure 1 shows hip angle in the standing position. The angles less than 180° were associated with increased lumbar lordosis in neutral standing, and increased lumbar kyphosis in full flexion. Descriptive statistics were used for all data. The Kolmogorov-Smirnov test was performed to assess the normality of the quantitative variables. The variables had normal distribution, thus the independent t-test was run for investigating the relationship of quantitative variables in LBP subjects and healthy controls. Additionally, for examining the relationship of these variables in the FP, AEP, and healthy group, one-way analysis of variance (ANOVA) was performed. If there were significant differences between the three groups, the post hoc of Tukey test was used. Statistical analysis was performed using SPSS, Version 20. Statistical significance was attributed to *P-values* less than *0.05*.

Results

Demographics

72 men satisfying the eligibility criteria signed the consent form to participate in the study. Their age, weight, height, and BMI are presented in Table 1. There were no significant differences in age, weight, height,

Table 3. Comparing of lumbar lordosis in normal group with the heterogeneous LBP group and the homogenous LBP group

Variable	FP	AEP	Heterogeneous LBP	Normal group	F^{Δ}	p^{Δ}	F^{Φ}	p^{Φ}
Neutral standing Lumbar angle	169.5 ± 6.10	165.92 ± 7.21	167.39 ± 6.94	164.69 ± 6.73	2.957	0.059	0.003	0.128
Full flexion Lumbar angle	172.65 ± 3.42	174.02 ± 3..37	173.46 ± 3.43	172.79 ± 3.90	1.193	0.309	0.538	0.464
Neutral standing hip angle	162.51 ± 5.34	159.04 ± 6.56	160.47 ± 6.27	161.55 ± 7.08	2.028	0.139	0.667	0.519
Full flexion hip angle	105.99 ± 9.65$^{\Diamond}$	100.15 ± 11.03	102.55 ± 10.78	96.42 ± 10.01	4.667	0.013*	0.140	0.026*

Homogenous LBP include: FP, Flexion pattern low back pain group and AEP, Active extension pattern low back pain group
$^{\Diamond}$ Significant difference compared with the control group in the post hoc test (*P<0.05*).
$^{\Delta}$: Comparison between subgroups (FP and AEP) and normal subjects $^{\Phi}$: Comparison between heterogeneous LBP and normal subjects

Table 4. Percentage of contribution of each quartile (Q)

Variable	FP	AEP	Heterogeneous LBP	Normal group	F^{Δ}	p^{Δ}	F^{Φ}	p^{Φ}
Lumbar Q1 contribution	19.04 ± 11.24	11.37 ± 18.65	18.81 ± 11.20	20.65 ± 15.38	0.167	0.846	1.822	0.569
Lumbar Q2 contribution	37.59 ± 15.46	32.24 ± 14.12	35.03 ± 14.69	15.64 ± 32.99	0.664	0.518	0.023	0.595
Lumbar Q3 contribution	18.68 ± 11.37	24.96 ± 15.14	22.38 ± 13.94	25.31 ± 15.05	1.548	0.220	1.244	0.424
lumbar Q4 contribution	9.15 ± 6.27	6.62 ± 4.41	7.66 ± 5.34	8.17 ± 7.16	1.196	0.309	2.294	0.737
Hip Q1 contribution	14.95 ± 8.35	14.05 ± 8.90	14.42 ± 8.61	14.27 ± 10.08	0.62	0.940	0.028	0.950
Hip Q2 contribution	41.99 ± 9.27$^{\Diamond}$	38.37 ± 7.31	39.86 ± 8.28	35.87 ± 8.15	3.048	0.054	0.455	0.062
Hip Q3 contribution	30.57 ± 8.45	31.15 ± 8.26	30.91 ± 8.26	31.38 ± 6.32	0.061	0.941	2.229	0.812
Hip Q4 contribution	10.85 ± 7.04$^{\Diamond}$	15.06 ± 8.54	13.33 ± 8.15	17.60 ± 9.48	3.502	0.036*	0.484	0.054

Abbreviations: FP, Flexion pattern low back pain group; AEP, Active extension pattern low back pain group; Q, quartile
$^{\Diamond}$ Significant difference compared with the control group in the post hoc test (*P < 0.05*).
$^{\Delta}$: Comparison between subgroups (FP and AEP) and normal subjects $^{\Phi}$: Comparison between heterogeneous LBP and normal subjects

and body mass index among the FP, AEP, and the healthy groups.

Comparison the lumbar region in healthy group with the heterogeneous LBP and the homogenous (FP and AEP) LBP groups

Although the mean of the lumbar lordosis was different between the groups, there was no statistically significant difference in the lumbar lordosis between the healthy group and the heterogeneous LBP group in standing and full trunk flexion positions (*P>0.05*). In addition, there was not any significant difference in lumbar lordosis between the healthy group and homogenous LBP group in standing and full trunk flexion positions (*P>0.05*), [Table 3].

Comparison hip angle for healthy group with the heterogeneous LBP and the homogenous (FP and AEP) LBP groups

In neutral standing position, there was no significant difference in hip angle between the healthy group and the heterogeneous LBP group, and between the healthy group and the homogenous LBP group (FP and AEP). In full trunk flexion, there was significant difference in hip angle between the healthy group and the heterogeneous LBP group (F=0.140, *P=0.026*). Comparison of the subgroups showed significant difference in the hip angle between the healthy group and FP group in full trunk flexion position (F=4.667, *P=0.013*). There was no significant difference in hip angle between the healthy group and AEP in the full trunk flexion position, [Table 3].

The "percentage of contribution of each quartile of lumbar ROM to the overall lumbar flexion ROM" in the healthy, heterogeneous LBP and homogenous (FP and AEP) LBP groups

There was no significant difference in the percentage of lumbar motion in each quartile of the total range of motion between the healthy group and the heterogeneous LBP group, and between the healthy group and the homogenous LBP groups (*P>0.05*), [Table 4].

The "percentage of contribution of each quartile of hip joints ROM to overall hip joints ROM" in healthy, heterogeneous LBP and homogenous (FP and AEP) LBP groups

The differences between the healthy group and the heterogeneous LBP group, and between the healthy group and the homogenous LBP groups in the percentage

Table 5. Lumbar/hip motion ratio

Variable	FP	AEP	heterogeneous LBP	Normal group	F^{Δ}	p^{Δ}	F^{Φ}	p^{Φ}
L/H ratio Q1	1.31 ± 1.18	1.00 ± 0.69	1.12 ± 0.92	1.47 ± 0.97	1.656	0.198	0.099	0.158
L/H ratio Q2	0.41 ± 0.35	0.98 ± 0.89	0.4(0.14,1.21)	1.03 ± 1.01	3.172	0.048*	0.645	0.274
L/H ratioQ3	0.22 ± 0.16	0.22 ± 0.12	0.22 ± 0.14	0.25 ± 0.12	0.382	0.684	0.401	0.384
L/H ratioQ4	0.26 ± 0.19	0.19 ± 0.14	0.22 ± 0.16	0.21 ± 0.21	0.918	0.404	0.961	0.935

Abbreviations: FP, Flexion pattern low back pain group; AEP, Active extension pattern low back pain group; L/H ratio, lumbar/hip motion ratio; Q, quartile.
$^{\Delta}$: Comparison between subgroups (FP and AEP) and normal subjects $^{\Phi}$: Comparison between heterogeneous LBP and normal subjects.

of hip movement in Q1 and Q3 of the total range of motion were not statistically significant (*P>0.05*).

In Q2 of the total range of motion, there was no difference between healthy group and heterogeneous LBP group (F=0.455, *P=0.062*). There was significant difference between the FP and the healthy groups (*P=0.43*), while p-value between and within the groups (FP, AEP and healthy group) was 0.054 (F=3.048). In Q4 of the total hip range of motion, there was not any significant difference between the healthy group and the heterogeneous LBP group (F=0.484, *P=0.054*), but there was significant difference between FP and healthy group (*P=0.029*), and p-value between and within groups (FP, AEP and healthy group) was 0.036 (F=3.502), [Table 4].

Lumbar/hip motion ratio (L/H ratio) of each quartile

There was no significant difference in the first, the third and the fourth quartiles of trunk flexion between the healthy group and the heterogeneous LBP group, and between the healthy group and the homogenous LBP groups (*P>0.05*). In the second quartile of the trunk flexion, there was not any significant difference between the healthy group and the heterogeneous LBP group (F=0.645, *P=0.274*), but there was the difference between healthy group and homogenous LBP groups (F=3.172, P=0.048). This difference was between the healthy group and FP (*P=0.071*), [Table 5].

Discussion

Lumbar lordosis angle is a determining factor in the clinical assessment of spinal disorders. The aims of the current study were to compare the results of posture and compensatory strategies of hip and lumbar region during trunk flexion between LBP and healthy subjects, and investigate the effect of LBP subgrouping on these results. The research outcomes revealed that the lumbar lordosis in healthy subjects is different from the pooled LBP in full flexion of the trunk. Subgrouping of pooled LBP showed that this difference is related to FP. Lumbar posture was associated with more lumbar kyphosis in FP. The findings from the current study demonstrated that in FP hip joints mobility increased in Q2 and decreased in Q4. The present results suggest that the Lumbar/hip motion ratio of FP in Q2 decreased and this confirms the increase of hip mobility.

Lumbar curvature

The current study shows lumbar lordosis did not differ between heterogeneous LBP and healthy subjects in neutral standing and the end of trunk flexion. It could be explained in part by the different measuring techniques used in this study (4, 18, 19). There was no difference between the lumbar posture of FP and the lumbar posture of AEP groups with lumbar posture of healthy subjects. One possible reason was that the patients had not any sustained posture and enough time that tissue crept. Another potential reason for these outcomes may be related to the small number of cases that participated in each subgroup. Although, the differences between degrees of lumbar posture was not statistically significant in the subgroups at the end of forward bending, the mean degree of lumbar posture had less kyphosis curvature in AEP, healthy group and FP, respectively. These results are consistent with the previous studies. They have shown that the lumbar posture in FP had more kyphosis in compassion with the normal and AEP at the end of the trunk flexion (2, 12, 20).

Hip angle

In neutral standing, no difference in hip angle was detected between pooled low back pain and healthy group. Also, the hip angle did not differ between LBP subgroups and healthy subjects, nonetheless the mean angle of the hip showed that the pelvis was more posteriorly tilted in FP and more anteriorly tilted in AEP compared to the healthy subjects. These results are in agreement with P. B. O'Sullivan classification system that described pelvic posture in subgroups. FP tend to hold their pelvis in posterior pelvic tilt and AEP commonly exhibit more anterior pelvic tilt (20). Also the results support previous investigations recognizing patients with FP displaying increased end-range lumbar flexion (21, 22).

In full flexion, the hip angle was different between pooled low back pain and healthy groups. It was shown that after subgrouping the heterogeneous LBP, this difference is related to FP. The results confirmed that kyphosis posture and posterior pelvic tilt are more common in FP patients (2, 23 24). As showed above, the lumbar spine of FP is more flexible during flexion than the hips (25).

Hip and lumbar quartiles

The results obtained from "hip joint" showed the Q2 and Q4 in FP are different from AEP and healthy group during forward flexion. The Q2 was increased and the Q4 was decreased in FP. In the "lumbar spine", there was no significant difference between LBP subgroups and healthy subjects in Q2 and Q4 but the mean values of FP were more than the AEP and healthy group. Thus, lumbar Q2 and Q4 have more mobility in FP group. This could be explained that in healthy subjects in Q4 of trunk flexion, the lumbar spine achieves its most extreme ROM, whereas the pelvis is giving work to terminal flexion to complete the full trunk flexion. Limited hip motion in Q4 may be a compensatory strategy for increased motion in the Q4 of lumbar spine (6). This agrees with the previous studies reporting FP group showed greater lumbar flexion near end-range lumbar spine flexion and lesser hip joints flexion. O'Sullivan introduced these motor control impairment (MCI) patterns and their clinical presentation (4, 26). Sahrmann's theory of the "relative flexibility or stiffness" could be linked to these findings (10). Decreased lumbar stability is due to only active, passive or neural element disorders or a combination of these disorders (27, 28). Previous data have suggested that erector spinae muscles endurance were decreased. This can lead to insufficient stability of spine during trunk flexion (9, 29). This could change neuromuscular strategies during the trunk flexion. Thus, hip extensor muscles try to compensate lumbar instability by increasing the tension of passive lumbopelvic structures, for example, the sacrotuberous ligament and the thoracolumbar fascia (29). Because the final half of the trunk flexion is finished fundamentally by anterior pelvic rotation, hip extensor muscles should control hip flexion and compensate lumbar instability (30). It is possible that increased tension in hip extensor muscles limits pelvic movement during flexion (29). Another possible neuromuscular compensation mechanism may be related to increased activation in abdominal muscles such as rectus abdominus and transverse fibers of internal oblique. Over-activity of these muscles can lead to posterior pelvic tilt and limit hip flexion ROM. This may be a substitution strategy for lumbar stabilization (31, 32).

In FP group, passive structures are damaged and show more neutral spinal repositioning deficits (26, 33). Passive spinal components are assumed as a basic part in the sensorimotor control of the spine, thus absence of sensory feedback from passive elements of the spine results in irregular local muscle tension and lumbar spine instability (34). It appears that hip extensors and erector spinae muscles are both anatomically and functionally connected throughout the trunk flexion task and compensate each other (29). Therefore, for controlling the lumbar spine instability, increment tension in hip extensor muscles or stiffness may occur in the posterior passive structure of hip joints at the end range of trunk flexion. It is possible that this mechanism limits hip flexion.

We should note that this increase in lumbar movement may be the results of hip restriction. It was suggested that back problem is connected with alterations in the mechanical qualities of the posterior hip tissues or changes in the level of activity of the hip extensors (35). It is also susceptible the neuromuscular system in pathologic condition give spinal stability via changing the timing and recruitment between the different muscles groups (31).

Although in this study the patients with radicular pain were excluded, it was suggested that the decrease of Q4 in the hip joints was to reduce the tension in neural tissues (sciatic nerve) in the posterior region of the hip joints (35).

L/H ratio quartiles

In FP, hip joint and lumbar region range of motion has been increased in Q2, and L/H ratio has been decreased (0.41 ± 0.35) in comparison with AEP and healthy groups. Q2 is near the middle range (neutral zone) (27, 28). During trunk flexion the torque of the trunk on the limbs, the movement velocity, and back extensor muscles activation are large in Q2. Thus, high neuromuscular control is needed. FP group has an inherent maladaptive motor control pattern and neutral zone instability at the lumbar spine (27, 28, 32). This may increase ROM in Q2. In this stage of the task, the lumbar spine should continue to move. It is possible that CNS intelligently increases hip ROM in Q2 for completing the movement and for preventing the more excessive movement and instability in Q2 of lumbar region. There are some studies that show the role of hip extensor muscles in lower back stabilization as well as in lumbopelvic rhythm (29). At the end of trunk flexion, the movement is finishing, but because of maladaptive motor control, excessive movement occurs in the lumbar spine (23). In this condition, CNS probably tries to stop the movement by limiting the hip motion.

Clinical implications

Clinically, it is essential to control the kinematic aspects of both the lumbar spine and hip joints for LBP and consider specific directional bias. It has been hypothesized that the subgrouping of NSCLBP subjects into the homogenous group may enhance treatment effect (36). It is suggested that in some parts of the ROM of a joint, stabilization exercise may be needed while in some its parts, mobility exercises may be required.

Limitations

Superficial placement of markers and skin movement throughout trunk flexion may have induced errors. In this study, the pathoanatomical aspects of patients were not considered. The low number of LBP was one of the important limitations of this study. The participants were only men, thus gender-related differences were not detected. Also, another possible limitation of this work was the recruitment of clinician as the main standard for subgrouping the patients. In our study, to decrease the bias in subgrouping of LBP, the musculoskeletal physiotherapist, who subgrouped the patients, was familiar with this classification system. To confirm the accuracy of subgrouping, the history and a video of patients lumbar movements and postures (trunk flexion and extension and sit to stand and single leg stand) was observed by another physical therapist that has been familiar with this classification system.

Future Research

Different functional tasks need to be investigated based on the specific directional bias in the LBP patients. It is suitable to study the changes in hip musculature structure and EMG activity of these muscles. Further research is needed to examine the effect of mobility and stability exercise in the specific angles of a joint.

Trunk flexion in this study is the more aggregating factor for FP group. Thus, it is reasonable that the FP group show more differences in variables. This study supports the subgrouping of NSCLBP patients and provides evidence to enhance the validity of the suggested classification system. Strategy and behavior to compensate or prevent further injury can be specified according to each part of joint ROM of the patients in the specific task. For instance, in a specific direction of joint movement, mobility decreases in some ranges while in some other ranges mobility increases. These different strategies and behavior may guide specific interventions in the movement chain. The theory of relative flexibility by Sahrmann can explain the increase of Q4 of lumbar region, but the decrease of Q2 of lumbar region couldn't be described based on this theory. Perhaps it is not applicable for all of the pathological conditions of human (10). It seems that this may be true for passive or rigid systems and for the end of the joint ROM that the roles of ligaments are significant. But a person with an intelligent CNS, tries to compensate or prevent more injury of the chain components (e.g., muscle, joint, nerve, etc.). This compensation can be done by selecting the best strategy in the other parts of the chain components based on the pathological condition. For example, when flexibility of a joint "increases" in a chain movement, the other parts of the chain may compensate it by "increasing" or "decreasing" their own flexibility.

Ethical approval

This research was reviewed and approved by the review board of Iran University of Medical Sciences.

The authors declare that they have no competing interests.

Acknowledgements

This study was derived from a thesis by Majid Shahbazi Moheb Seraj. We appreciate the efforts of Dr. Akhlaghi for statistical counseling, Dr. Ravari for numerical computation with MATLAB, and Mr. Ghazi for his support in data collection and formatting.

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