Factors affecting shoulder–pelvic integration during axial trunk rotation in subjects with recurrent low back pain

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Abstract

Introduction Shoulder–pelvic integration could play a central role in the control of dynamic posture and movement. However, kinematic coordination during axial trunk rotation has not been carefully investigated in subjects with recurrent low back pain (LBP). The purpose of this study was to compare the maximum rotational angles of the shoulders and pelvis in the transverse plane between subjects with and without recurrent LBP.

Materials and methods A total of 38 age-matched subjects (19 control subjects: 69.00 ± 5.75 years old and 19 subjects with LBP: 68.79 ± 5.40 years old) participated in the study. The axial trunk rotation test was conducted in the upright position with bilateral hips and knees fully extended and both feet shoulder width apart.

Results The results of this study indicated that there was a difference in pelvic girdle rotation between groups (100.79 ± 26.46 in the control group, 82.12 ± 23.16 in the LBP group; $t = 2.31$, $p = 0.02$); however, there was no difference for the shoulder girdle (177.63 ± 36.98 in the control group, 156.42 ± 30.09 in the LBP group; $t = 1.91$,

$p = 0.06$). There were interactions with age ($F = 9.27$, $p = 0.004$) and BMI ($F = 7.50$, $p = 0.01$) with the rotational angles of the shoulder and pelvis.

Conclusion These results indicated a different pattern of trunk rotation movement with the age and BMI serving as important factors to consider for recurrent LBP. The results of our study also indicated a different pattern of shoulder and pelvic coordination with age and gender. Clinicians need to consider the consequences of limited shoulder–pelvic rotational angles, especially limited rotational angle on the pelvis during trunk axial rotation. Further studies are required to determine the causes of the underlying problems for clinical decision-making and altered shoulder–pelvic rotation in subjects with recurrent LBP.

Keywords Motion analysis · Spinal inflexibility · Axial rotation · Kinematics · Hip joint · Lumbar spine

Introduction

It has been reported that impaired trunk movement in subjects with low back pain (LBP) results in limited range of motion (ROM) of the trunk or abnormal patterns of lumbo-pelvic motion [1, 2]. Several other investigators have also reported decreased flexibility and back muscle tightness. These changes in movement patterns produced less transverse plane rotational torque based on the stability of the coordination pattern and the unloaded kinematics [3, 4]. As a result, it is important to increase the flexibility of the trunk to demonstrate integrated functional performance in subjects with recurrent LBP during trunk rotation. The coordinated functional trunk motion should be incorporated with shoulder and pelvic ROM for continual motion and flexibility of the thorax. However, there is a lack of investigation

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regarding coordinate stability of shoulder and pelvic motion for daily activities.

Since axial rotation of the torso is a risk factor for recurrent LBP, bilateral shoulder and pelvic motion could be crucial for dynamic balance [5–7]. The co-ordination of trunk motion during dynamic activities enhances the flexibility and stability of the whole spine [8–10]. It has been known that individuals with LBP raise unbalanced muscle activity which could prompt a decreased, uncoordinated, and asymmetric bracing effect [11]. Therefore, a kinematic analysis for postural alignment might be helpful in understanding rehabilitation strategies for patients experiencing limited rotation of the shoulder and pelvic girdle during axial trunk rotation. Since the pelvis could be considered an anatomical reference frame, elementary trunk rotation between the pelvis and shoulder girdles should be understood carefully for clinical decision-making.

The patterns of trunk motion have a spiral, diagonal direction, and the performance of these patterns may permit muscles to act in ways that are close to the actions and movements of the whole spine [12]. Decreased trunk ROM might result in stiffened passive structures, and the function of the lumbar spine might be altered based on the stiffened dominance side of the hip joint. Therefore, the patterns are more critical for shoulder and pelvic integration for performance enhancement than conventional single-plane or single-direction movements. However, no studies have examined bilateral shoulder and pelvic excursions during axial trunk rotation tasks.

Postural control might require a more complex process involving integrated motor function for impaired balance performance in subjects with LBP [13, 14]. Failing to explicitly consider individual characteristics of kinematic changes in shoulder–pelvic movements, such as gender, age, height, and body weight, may result in the risk of low back dysfunction and trunk muscle imbalance. These demographic characteristics are required to quantify biomechanical changes by kinematic analysis in subjects with recurrent LBP.

In order to consider consequences of the limited shoulder–pelvic rotational angles, different compensatory strategies of pelvic motion might be required. However, most movement studies examined sagittal plane imbalance [15–17] without examining interactions in the other planes of motion, which are used for functional activities of daily moving. Indeed, there is a lack of comprehensive understanding between shoulder and pelvic function based on the transverse plane. Therefore, the purpose of this study was to compare different ROM on kinematic changes of the shoulder and pelvic joints during axial trunk rotation activities in standing. Overall kinematic changes were also investigated while considering demographic factors, such as gender, age, and body mass index (BMI), in subjects with recurrent LBP.

Methods

Subjects

Subjects were recruited from a health promotion club in Seoul, Korea. Subjects who expressed interest in the study became eligible. Only subjects with recurrent LBP that had been enrolled in the club were contacted to minimize the risk of confounding effects over the study period as well as to increase the internal validity of the data. Those subjects who met study inclusion criteria received information about the study and signed a copy of the Institutional Review Board approved consent form. The subjects with LBP did not have acute symptoms during the test. Therefore, the test was conducted as a standardized procedure and minimized a direct effect of pain/disability.

The volunteers for this study were subjects who presented with recurrent LBP, met study inclusion criteria, and experienced a repeated disturbing impairment or abnormality in the functioning of the low back for more than 2 months prior to the start of the study [18]. Subjects were eligible to participate if they: (1) were 21 years of age or older, (2) had recurrent LBP on both sides of the back for more than 2 months without pain referral into the lower extremities, (3) were right leg dominant, and (4) had no structural deficits such as scoliosis, kypohsis, or spondylitis.

Subjects were excluded from participation if they: (1) had a diagnosed psychological illness that might interfere with the study protocol, (2) had overt neurological signs such as sensory deficits or motor paralysis, (3) had no acute symptoms of LBP during the moment of the test, or (4) were pregnant. Participants were withdrawn from the study if they requested to withdraw. In our study, the right lower extremity was regarded as the dominant side for all subjects since they preferred to kick a ball with this limb [19, 20]. The control group was recruited from the community and included age-matched subjects who did not suffer from LBP.

Outcome measures

Pain/disability was inferred from self-reported scores on the Oswestry Low Back Disability Index (ODI). The ODI is one of the most frequently used tools for measuring chronic disability [21]. A sum is calculated and presented as a percentage, where 0 % represents no disability and 100 % the worst possible disability.

The axial trunk rotation test was conducted at the Motion Analysis Laboratory. This test was standardized for the examiner to accurately measure all the participants. The participants performed five trials in which they were instructed to stand quietly in the upright position on a force plate surface with their eyes opened and bilateral hips and knees fully extended with both feet shoulder width apart.

Fig. 1 Axial rotation test in standing position. A subject stands with both legs fully extended with a stick bar at arm's length from the body and performs axial rotation activities five times repeatedly. During the test, subjects maintain standing stability while the reflective markers collect kinematic data from the three axes of the spine. (X frontal, Y sagittal, Z transverse planes)

Fig. 2 An example of the ROM (y axis: degrees) differences between the shoulder and pelvis in the transverse plane during trunk axial rotation. The control group demonstrated greater ROM than subjects with LBP in the transverse plane

The subjects rotated their trunks on both sides in the transverse plane (clockwise and counter clockwise axial rotation) while holding a stick bar at the height of their shoulders (Fig. 1). The trunk rotations were defined as voluntary exertions, and the subjects were instructed to turn their shoulders, hips, and knees without moving their feet. They were given disposable hospital slipper socks with nonskid bottoms to wear during the test and had the Helen Hayes full body (with head) reflective marker set attached to specific sites on their bodies [24–26].

The body segments were modeled as rigid bodies, and the relative rotation angle was taken from a fixed point in the center of the joint. The kinematic angles were applied to describe relative rotations of one segment with respect to another reference segment. Therefore, three-dimensional shoulder and pelvic angles were derived from the relative orientation based on the spine axis. The method of computation was based on mathematical techniques, and kinematic joint angles were derived from the direction cosine matrices of the sensors [22, 23]. The maximum angle was measured based on the direction of the rotation at 70° at a self-selected speed

(0.8 ± 0.2 m/s). Therefore, the maximum values were actually the average angle of the five repeated trunk rotations to each direction (Fig. 2).

Synchronized kinematic data of joint angles were recorded and processed by six digital cameras capturing three-dimensional full body kinematic motion (Motion Analysis Corporation, Santa Rosa, CA, USA) sampling at 120 Hz. All kinematic data of joint angles were time synchronized within the test cycle. Digital video data were collected and tracked using EVA 5.20. Digital video were then imported into Orthotrac 5.2 (Motion Analysis Corporation, Santa Rosa, CA, USA).

The validity of outcome measurements has been reported in previous studies from our motion laboratory [2, 24, 25]. For the reliability component of the study, subjects completed the axial trunk rotation test five times during the session, and the average of the results was taken to avoid any changes or procedural discrepancies. Subjects were given at least 1 min to rest between each test, and there were two raters involved during the procedure. Each rater was blinded to the results of the other since they did not

share the values of the results. The method of computation was based on mathematical techniques, and kinematic joint angles were derived from the direction cosine matrices of the sensors [22, 23]. The reliability of the motion analysis system has also been reported and confirmed with previous studies [2, 24, 26].

Statistical analysis

Statistical analyses were completed using SPSS 16 (SPSS, Chicago, IL, USA). Normality was assessed for each of the dependent variables. A repeated measure analysis of variance (ANOVA) was used for each dependent variable (body region: shoulder and pelvic ROM) to determine the main effects of group. The independent *t* test was used to analyze dependent variables between groups. The gender, age, and BMI variables were used as covariates to eliminate confounding effects. For all statistical tests, type I error rate was set at 0.05.

Results

Subjects

A summary of subject demographics and the relationship of groups are summarized in Table 1. In total, 38 subjects enrolled in the study, including 19 control subjects and 19 subjects with LBP. The average age of the subjects was 68.89 ± 5.51 years and ranged from 56 to 79 years. The LBP group was slightly younger (68.79 ± 5.40 years) than the control group (69.00 ± 5.75 years), but there was no significant difference between groups ($t = 0.11$, $p = 0.90$). The BMI was compared between the control group (18.75 ± 1.98) and the LBP group (20.02 ± 2.83);

however, there was no difference ($t = -1.67$, $p = 0.10$). The ODI scale for the subjects with LBP was 20 %, which indicates moderate disability (20–40 %) [27].

Difference of kinematic displacements between shoulder and pelvic rotation

In Fig. 3, the maximum angles for the shoulder and pelvis were analyzed during axial trunk rotation by a mixed repeated measure ANOVA. The results indicated that there was a significant difference in shoulder–pelvis rotation angles ($F = 19.94$, $p = 0.0001$). Specifically, it was evident that the pelvic ROM decreased in subjects with LBP ($82.12^\circ \pm 23.16^\circ$) compared with the control subjects ($100.79^\circ \pm 26.46^\circ$). This difference was statistically significant ($t = 2.31$, $p = 0.02$).

Fig. 3 The shoulder and pelvic ROM differences during axial trunk rotation between control and LBP subjects. The results of this study indicated that there was a significant difference between shoulder and pelvic rotation angles ($F = 19.94$, $p = 0.0001$)

Table 1 Summary of demographics and bivariate relationship of subject groups

Variable	Total	Control	LBP	Statistic	<i>p</i>
Number of subjects	38	19	19		
Gender					
Female	26	11	15	$\chi^2 = 1.94$	0.15
Male	12	8	4		
Age (years)					
Range	56–79	56–78	58–79	$t = 0.11$	0.90
Mean ± SD	68.89 ± 5.51	69.00 ± 5.75	68.79 ± 5.40		
BMI					
Range	15.29–24.48	15.41–21.78	15.29–24.48	$t = -1.67$	0.11
Mean ± SD	19.40 ± 2.49	18.75 ± 1.98	20.09 ± 2.83		
ODI					
Range	N/A	N/A	0–0.37	N/A	N/A
Mean ± SD			0.20 ± 0.48		

BMI body mass index, ODI Oswestry disability index

The maximum shoulder ROM was greater than the pelvis, and the control group ($177.63^\circ \pm 36.98^\circ$) demonstrated greater shoulder ROM than the subjects with LBP ($156.42^\circ \pm 30.90^\circ$). However, there was no difference between groups ($t = 1.91$, $p = 0.06$). Other covariates, such as age and BMI were analyzed. There was a significant interaction between body region (shoulder and pelvis) and age ($F = 9.12$, $p = 0.005$). There was also significant interactions with BMI ($F = 7.25$, $p = 0.01$).

The shoulder and pelvic rotational angles (body region) were compared between groups. In Fig. 4, there was a significant interaction between body region and age ($F = 14.74$, $p = 0.001$). As shown in Fig. 5, the shoulder and pelvic ROM were significantly different ($F = 6.24$, $p = 0.01$) between genders.

The correlations of demographic factors were considered with shoulder and pelvic ROM changes between groups. In the control group, the shoulder ROM was negatively correlated with age ($r = -0.74$, $p = 0.001$), but BMI ($r = 0.05$, $p = 0.83$) was not significantly correlated. For the pelvic ROM, there was a negative correlation with age ($r = -0.72$, $p = 0.001$), but BMI ($r = 0.25$, $p = 0.30$) was not significantly correlated. There was a significantly positive correlation between shoulder and pelvic rotational angles ($r = 0.91$, $p = 0.001$).

For the LBP group, there were no significant correlations between shoulder ROM and other factors. The shoulder ROM was negatively correlated with age ($r = -0.41$, $p = 0.08$) and not significantly correlated with BMI ($r = -0.07$, $p = 0.78$). For the pelvic ROM, there was a negative correlation with age ($r = -0.16$, $p = 0.52$), and BMI ($r = -0.21$, $p = 0.40$) was not significantly correlated.

Fig. 4 The interaction with age for ROM between control and LBP subjects. There was a significant interaction between body region and age ($F = 14.74$, $p = 0.001$)

Fig. 5 The shoulder and pelvic ROM differences during axial trunk rotation between genders. The results indicated that there was a significant gender difference between shoulder and pelvic rotation angles ($F = 6.24$, $p = 0.01$)

There was no significant difference between shoulder and pelvic rotational angles ($r = -0.80$, $p = 0.74$).

Discussion

The purpose of this study was to compare the different rotational angles of kinematic changes on the shoulder and pelvis during axial trunk rotation in the transverse plane while considering demographic factors in subjects with recurrent LBP. The results of our study indicated a different pattern of shoulder and pelvic coordination with age and gender. There was also a significant interaction between body region (shoulder and pelvis) and age as well as BMI.

Different kinematic strategies could be applied during trunk axial rotation in order to cope with the underlying problems present in subjects with recurrent LBP. Our study was conducted to clarify the transverse plane of shoulder and pelvic coordination. The validity of the results was considered for the spinal stability in the pelvic and lumbar spine regions during trunk axial rotation [24, 28]. The test was conducted by the standardized procedure, and the average of the maximum angles with repeated trials was checked for consistency.

The results of our study indicated that there was a difference in pelvic girdle rotation between groups; however, there was no difference for the shoulder girdle. It has been reported that there was an increased asymmetry in trunk rotation between the phase-relations of the left and right sides of the body during ambulation in subjects with LBP [28]. Another study also reported increasing lumbar and hip movements in the frontal and horizontal planes of

motion [29]. However, there was no specific kinematic measure for the differences between the shoulder and pelvis during axial trunk rotation.

One study reported postural static and dynamic defects, particularly in the sagittal plane, which were affected by spinal curvature abnormalities and relevant motor dysfunction of the lumbo-pelvic rhythm [30]. However, typical compensatory mechanisms of the trunk should be combined with transverse plane motion. The results of this study also indicated that there was a significant difference in shoulder–pelvic rotation angles. The control group demonstrated significantly increased pelvic rotation compared to the subjects with LBP although there was no statistical difference between groups for the shoulder. Among the demographic factors, age and gender demonstrated significant interactions with shoulder–pelvic angle changes. As a result, it is important to examine stiffened functional motion in the pelvic region while considering the whole spine to understand compensatory mechanisms in addition to poor proprioception in subjects with recurrent LBP [2, 25].

Overall, our findings suggest that decreased spinal angular motion in subjects with recurrent LBP might limit the coordination of pelvic flexibility as well as compensation from possible uncoordinated proprioceptive feedback. Therefore, it could be assumed that stiffened viscoelastic characteristics might be responsible for increases in lumbar stiffness, especially when considering age and gender differences. It is important to understand the potential benefit of bilateral pelvic flexibility strategies based on patho-mechanical spinal movement patterns regardless of anthropometric factors to assist in rehabilitation intervention.

It has been reported that there are gender differences in loading patterns and pain generating pathways when considering the mechanical mechanisms of reducing the risk of injury as well [31]. Therefore, gender-dependent strategies should be considered to reduce the risk of injury or aggravation of an existing injury [32]. It is also possible that different tasks or daily activities besides gender differences could interact with other demographic factors. The maximum shoulder ROM was greater than the pelvis, and the rotational angle differences were considered with the covariates. There was a significant interaction between body region (shoulder and pelvis) and age as well as with BMI.

The stiffened functional motion is important to examine to understand compensatory mechanisms in subjects with recurrent LBP. In order to maintain postural stability during axial trunk rotation, the body requires not only reliable sensory feedback or muscle activation from all involved joints but also the sensitive response of proprioceptive receptors. The efficacy of spinal coordination of shoulder and pelvic kinematic integration during axial trunk rotation

could be affected by postural balance and neuromuscular performance. The uncoordinated and unbalanced axial rotation of the trunk might be a risk factor in connection with spinal injuries during twisting activities. It is crucial to maintain stability and functional mobility of the spine under rotational activities which might require a complex process involving integrated shoulder and pelvis function. Therefore, the effect of axial trunk rotation might result in stiffened passive structures of the characterized pattern by more rigid, less flexible pelvis–thorax coordination. The absence of significant differences in the rotations could be kinematic problems in subjects with recurrent LBP of the component. These results suggest that coordination measures are more adequate in assessing quality of rotation of the torso for the individual segment rotations in subjects with recurrent LBP.

Subjects with recurrent LBP were able to complete a task by increasing lumbar and hip movements in the frontal and horizontal planes of motion while limiting movements in the sagittal plane [33, 34]. This uncoordinated axial rotation of the trunk might be a risk factor in connection with spinal injuries during twisting activities. The ROM of the trunk might be affected by increased stiffness due to a repeated pattern of movements. These results considered that the shoulder and pelvic regions should be further investigated three-dimensionally while considering biomechanical effects for trunk rotational displacement. The early detection of stiffened hip joints and overall spinal flexibility might be important to understand compensatory mechanisms and prevent back injuries.

One limitation of this study was the selection of the group, which included ‘volunteers’. Increasing the number of subjects would serve to increase the power of the study. The other limitation of this study was that the individual subjects might vary even within a healthy population. It would be beneficial to quantify inter-/intra-subject variability, which can provide the efficacy of the test. These motion patterns might be assumed to be functional compensation strategies following altered neuromuscular coordination. This is probably the consequence of an imprecise internal estimate of compensation due to reduced accuracy in the sensory integration process. Therefore, subgroup analyses would provide more accurate resolution of the intra-/inter-variability for future studies.

Despite these limitations, quantification of hip motion deficits is valuable to a number of populations. It is unknown whether reduced rotational angles are consequences or causes and, therefore, was not the scope of this study. However, the reduced rotational angle in the pelvis could be of particular interest to the clinician who commonly evaluates patients with hip and spine problems and assesses progress in the rehabilitation setting. Follow-up, randomized controlled trials are needed to investigate the

characteristics of three-dimensional shoulder and pelvic flexibility as well as spinal compensation strategies to enhance both biomechanical and neuromuscular aspects of movement patterns.

Conclusion

Our study demonstrated a different pattern of shoulder and pelvic coordination in subjects with recurrent LBP. The functions of the shoulder and pelvis might be altered based on gender and age although some variability exists between and within subjects. The results also indicated a different pattern of trunk rotation movement due to age and BMI. Clinicians need to consider decreased pelvic rotation compared with shoulder ROM in the transverse plane in LBP patients. Clinicians need to apply gender differences in kinematic strategies during trunk axial rotation to cope with underlying problems in subjects with recurrent LBP. Further studies are required to investigate three-dimensional shoulder–pelvic patterns of axial trunk ROM which might result in stiffened passive structures of the spine.

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Conflict of interest None.

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