

Kinematic analysis of symmetric axial trunk rotation on dominant hip

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Abstract—Axial rotation of the trunk has been reported as a significant risk of low back dysfunction. However, a lack of biomechanical investigation exists that explains how twisting is accomplished with simultaneous asymmetric handling between the hip joints and lumbar spine. We used a three-dimensional motion analysis to measure movements of the bilateral hips and lumbar spine. Forty-four persons participated in the study, and the results indicated that spinal range of motion (ROM) was significantly different based on dominance ($F = 198.83$, $p = 0.001$), region \times dominance ($F = 14.21$, $p = 0.001$), and dominance \times dimension ($F = 141.08$, $p = 0.001$). We also found a three-way interaction between region \times dominance \times dimension ($F = 26.30$, $p = 0.001$). These results indicated that the motion of the transverse and sagittal planes significantly increased when the participants attempted to rotate their hips, especially on the nondominant side. Decreased axial trunk ROM on the side of dominance might stiffen passive structures of the hip joints. The functions of the hip joints and lumbar spine might be altered three dimensionally based on the side of dominance.

Key words: axial rotation, biomechanics, dominance, hip, kinematic changes, motion analysis, range of motion, rehabilitation, spinal inflexibility, trunk.

INTRODUCTION

Axial twisting of the torso has been identified as a significant risk of low back pain (LBP), which is the most common type of musculoskeletal degeneration in our society [1–3]. The coordination of trunk motion during

functional movements depends on flexibility and stability of the hips, with optimal range of motion (ROM) within the whole spine [4–6].

A high correlation exists between hip motion and total axial rotation, thus suggesting that improving flexibility of the hips would alleviate pain and its recurrent episodes [7]. Postural control might require a more complex process involving integrated motor function for impaired balance performance in participants with LBP [8–9]. For example, participants with LBP who have radiating leg pain demonstrated limited movement during physiological movements of the hip and lumbar spine [10]. Other investigators also reported decreased trunk flexibility and low back muscle stiffness in participants with LBP [11–14]. As a result, investigating muscular control in and around the trunk and hip joints is important in developing rehabilitation strategies for preventing back injury [15–18].

Previously, our laboratory reported that investigators should methodologically consider hand dominance for back pain research [19]. In lieu of this dominance, failing to consider the lower-limb dominance explicitly along

Abbreviations: 3-D = three-dimensional, ANOVA = analysis of variance, LBP = low back pain, ROM = range of motion.

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with the side assessed may confound results for muscle-activity-related outcomes. However, a lack of kinematic analysis exists for postural alignment with a specific spine model, which has not been comprehensively investigated between the hip joints and lumbar spine with neuromuscular functional activities.

Therefore, quantifying three-dimensional (3-D) changes is necessary in angular displacement of the hip joints by motion analysis with a biomechanical spine model in participants with LBP. Since several factors are related to motion changes of the hip joints, effects of dominant side should be investigated while the whole spine during trunk axial rotation is considered. Maintaining stability and normal function of the spine is crucial under static and dynamic conditions. Axial rotation of the trunk with simultaneous loads may be a significant risk of low back injuries [20–21]. The deficits could include spinal inflexibility, different compensatory strategies of the hip joints, and abnormal patterns of postural responses. However, lack of a comprehensive examination of postural alignment exists between the whole spine and hip joints based on 3-D kinematic changes.

In our study, we investigated overall kinematic changes while considering anthropometric factors such as age, height, and body weight. Therefore, this study compared the effects of the dominance of 3-D kinematic changes on the lumbar spine and hip joints from the axis of the core spine in nondisabled participants during axial rotation activities while standing.

METHODS

Participants

Participants were volunteers from a health promotion club in Seoul, Korea, and we contacted them to minimize the risk of confounding effects and to increase internal validity of the data [22]. Those volunteers who met study inclusionary criteria received information regarding the purpose and methods of the study before signing a copy of the institutional review board approved consent form.

Volunteers for this study were participants without LBP who did not experience a disturbing impairment or abnormality in the functioning of the low back during the previous 2 months. Volunteers were included in this study if they (1) were 18 years of age or older, (2) did not experience LBP or pain referral in the lower limbs, (3) reported no symptoms of back or hip pain during

axial trunk rotation activities, and (4) were right-limb dominant [23]. Volunteers were excluded from participating if they (1) had a diagnosed psychological illness that might interfere with the study protocol, (2) had overt neurological signs (sensory deficits or motor paralysis), and/or (3) were pregnant. Participants were withdrawn from the study if they requested to withdraw [22]. All participants completed a survey and questionnaire that included health information regarding anthropometric factors such as age, height, and weight.

Outcome Measures

The axial trunk rotation test was standardized so that the examiner could accurately measure all the participants. The participants performed five trials in which they were instructed to stand quietly upright with their eyes open and hips and knees fully extended, with both feet shoulder width apart. Participants rotated their trunks in the transverse plane (right and left axial rotation) as they twisted their trunks to both sides while holding a stick bar at the height of their shoulders.

The participants stood upright on a force plate surface and performed five trials of the trunk rotation test at a self-selected speed (0.8 ± 0.2 m/s). The trunk rotation included voluntary exertions in which participants turned in the counterclockwise and clockwise directions. The participants were instructed to turn their shoulders, hips, and knees without moving their feet. They were given disposable hospital slipper socks to wear during the test and had the Helen Hayes full-body (with head) reflective marker set attached to specific sites on their bodies with adhesive tape rings [22–23].

In **Figure 1**, we calculated the core spine axis based on the coordinates between the center of the pelvic and shoulder planes. The lumbar spine is the line between the center of the second sacrum and the twelfth thoracic spine levels [22]. The 3-D planes included the anterior-posterior (frontal), mediolateral (sagittal), and vertical (transverse) axes from the core spine axis and were calculated during trunk axial rotation. We calculated the average angular data for five complete trunk axial rotations (counterclockwise followed by clockwise) during the isolated trunk rotation task.

We recorded and processed synchronized kinematic data of joint angles using six digital cameras, capturing 3-D full-body kinematic motion sampling (Motion Analysis Corporation; Santa Rosa, California) at 120 Hz. All kinematic data of joint angles were time-synchronized within

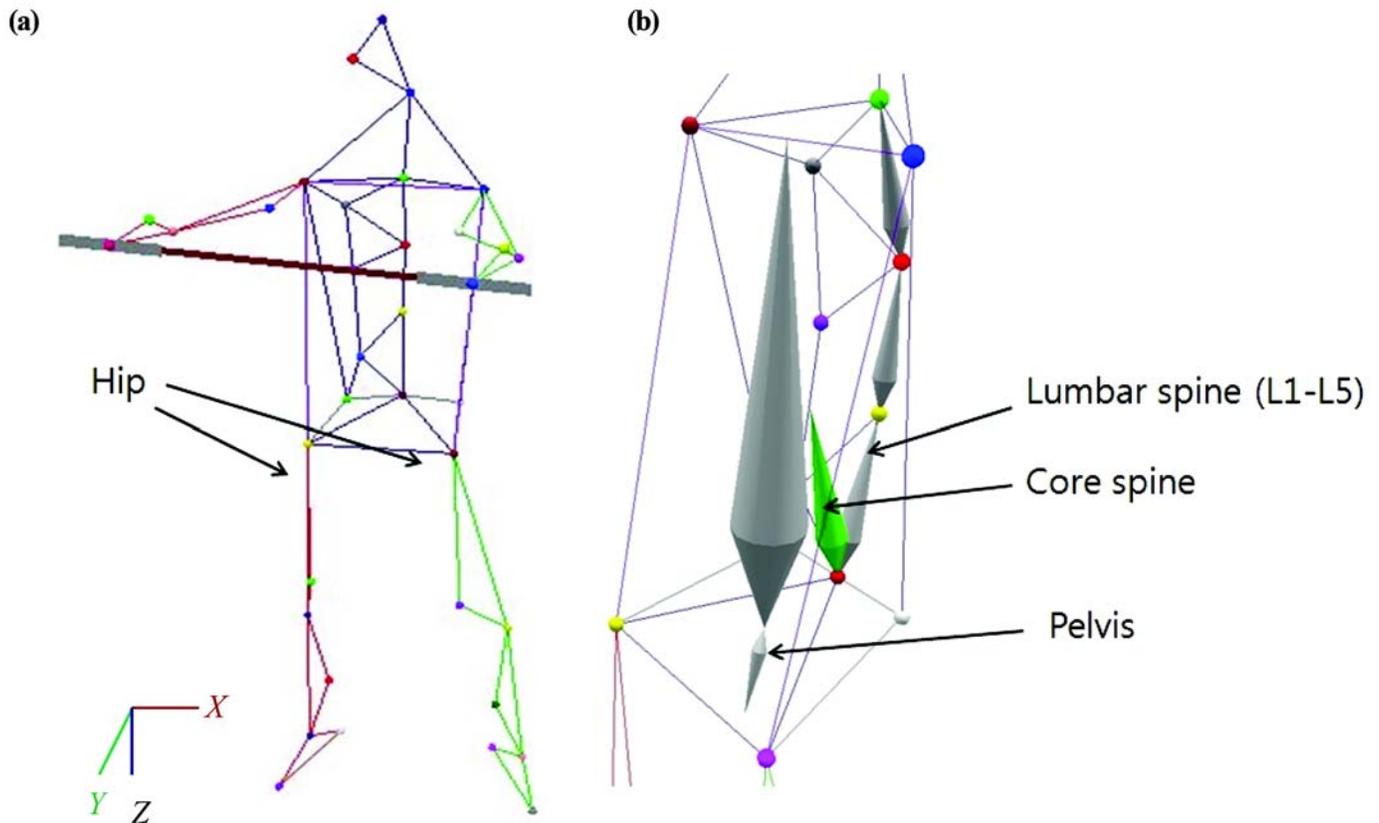


Figure 1.

Axial rotation test in standing position. (a) Participant stands with both legs fully extended with stick bar and performs axial rotation activities five times repeatedly. During testing, (b) participants maintain standing stability while reflective markers collect kinematic data from three spine axes (X = frontal, Y = sagittal, Z = transverse planes). L1–L5 = lumbar vertebrae 1–5.

the test cycle. In addition, we collected and tracked digital video data using EVA 5.20 (Motion Analysis Corporation) and then imported the data into Orthotrak 5.2 (Motion Analysis Corporation) [22–23].

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. We applied the kinematic angles to describe relative rotations of one segment with respect to another reference segment. Therefore, we derived lumbar spine angles from the relative orientation based on the core spine axis. The hip joint angle was taken from the hip and sacral sensors on the basis of the core spine axis. The method of computation was based on mathematical techniques, and kinematic joint angles were derived from the direction cosine matrixes of the sensors [24–25]. We measured maximum angle based on the direction of the rotation, which was either counter-clockwise or clockwise at 70° . Therefore, the maximum

values were actually the average angle of the five repeated trunk rotations to each direction.

We also applied participant handedness in this study since the previous study confirmed that handedness could be a confounding factor for a back muscle study [19]. In addition, in the current study, we regarded the right lower limb as the dominant side for all participants because they preferred to use the right limb to kick a ball [26–27].

Statistical Analyses

We completed statistical analyses using SPSS 16 (SPSS; Chicago, Illinois). Normality was assessed for each of the dependent variables. We used an independent t -test to analyze dependent variables based on each group (male and female). We used a repeated measures analysis of variance (ANOVA) for each dependent variable to determine the main effects of each group. To eliminate

confounding effects, we used the age, height, and weight variables as covariates. We evaluated all continuous dependent variables using the general linear model [28]. For all statistical analyses, type I error rate was set at 0.05.

RESULTS

Participants

In total, 44 persons participated in the study, including 28 females and 16 males. The average age of the participants was 40.8 ± 18.2 years and ranged from 21 to 72 years. The female group was slightly younger (39.7 ± 18.7) than the male group (43.1 ± 17.4), but no significant difference existed between groups ($\chi^2 = 28.13$, $p = 0.30$). The male participants were slightly taller (172.5 ± 6.9 cm) than the female participants (160.8 ± 5.3 cm), although height was not significantly different between groups ($\chi^2 = 27.65$, $p = 0.32$). Weight was not significantly different between groups ($\chi^2 = 25.76$, $p = 0.26$).

Sex Differences in Kinematic Displacements

In **Table 1**, the average angles for the dominant and nondominant hips as well as the lumbar spine were compared between sexes during axial trunk rotation. Data show that the male group demonstrated decreased angular motion for both hips compared with that of the female group, especially in the transverse axis (Z) of the lumbar spine ($15.48^\circ \pm 5.21^\circ$ vs $11.51^\circ \pm 5.07^\circ$). This difference was statistically significant between sexes (t -value = 2.46, $p = 0.02$). However, the other angular motions were not significantly different between sexes.

Group Analysis of Spinal Kinematic Data

For the effect of group differences on kinematic data during the axial rotation test, **Table 2** shows the repeated measures ANOVA that was conducted for comparing the ROM differences of the dominant and nondominant sides of the lumbar spine as well as both hips. The spinal ROM was significantly different between dominance ($F = 198.83$, $p = 0.001$), region \times dominance ($F = 14.21$, $p = 0.001$), and dominance \times dimension ($F = 141.08$, $p = 0.001$). We found a three-way interaction between region \times dominance \times dimension ($F = 26.30$, $p = 0.001$). In **Figure 2**, 3-D spinal ROMs for axial trunk rotations were summarized for the dominant and nondominant side differences for the lumbar spine as well as both hip joints.

We found a significant interaction in age, dominance, and dimension ($F = 4.64$, $p = 0.03$). However, we found no age interactions with region ($F = 0.01$, $p = 0.74$), dominance ($F = 0.04$, $p = 0.84$), or region \times dominance ($F = 0.02$, $p = 0.89$). In addition, we found no significant interaction in dominance \times dimension ($F = 2.65$, $p = 0.11$) during axial trunk rotation. Overall, the combined effect of dominance \times dimension demonstrated an interaction with age.

DISCUSSION

While considering anthropometric factors, this study compared the side effects of dominance of 3-D kinematic changes on the hip joints and lumbar spine from the axis of the core spine during axial rotation activities in participants while standing. Recent studies indicated that postural chain mobility might be necessary for spinal

Table 1.

Kinematic angular displacement ($^\circ$) for each spinal region and plane (X, Y, and Z) of dominant and nondominant sides during axial rotation test of male ($n = 16$) and female groups ($n = 28$).

Side	Female (Mean \pm SD)	Male (Mean \pm SD)	t-Value	p-Value
Dominant				
Lumbar X	15.29 \pm 6.30	13.49 \pm 5.41	0.98	0.32
Lumbar Y	5.65 \pm 3.24	4.83 \pm 2.46	0.93	0.36
Lumbar Z	15.48 \pm 5.21	11.51 \pm 5.07	2.46	0.02*
L Hip X	13.31 \pm 6.76	12.89 \pm 6.56	0.20	0.84
L Hip Y	7.93 \pm 4.86	7.87 \pm 4.01	0.04	0.96
L Hip Z	49.42 \pm 9.36	48.19 \pm 10.11	0.39	0.69
R Hip X	10.50 \pm 5.92	10.76 \pm 5.12	-0.15	0.89
R Hip Y	12.76 \pm 5.50	12.40 \pm 5.26	0.21	0.83
R Hip Z	48.85 \pm 10.11	51.78 \pm 10.13	-0.91	0.36
Nondominant				
Lumbar X	16.85 \pm 4.29	14.34 \pm 3.96	-1.95	0.06
Lumbar Y	7.12 \pm 4.71	5.46 \pm 3.65	-1.29	0.20
Lumbar Z	10.76 \pm 4.03	11.34 \pm 6.05	-1.29	0.73
L Hip X	11.97 \pm 6.03	9.95 \pm 6.15	-1.06	0.29
L Hip Y	14.11 \pm 5.98	14.13 \pm 4.65	-0.02	0.98
L Hip Z	45.89 \pm 8.36	48.79 \pm 13.28	-0.79	0.43
R Hip X	8.03 \pm 4.80	7.30 \pm 5.11	-0.46	0.64
R Hip Y	10.16 \pm 4.80	7.30 \pm 5.10	0.41	0.68
R Hip Z	55.89 \pm 21.20	44.98 \pm 13.66	-1.55	0.12

* $p < 0.05$.

L = left, R = right, SD = standard deviation.

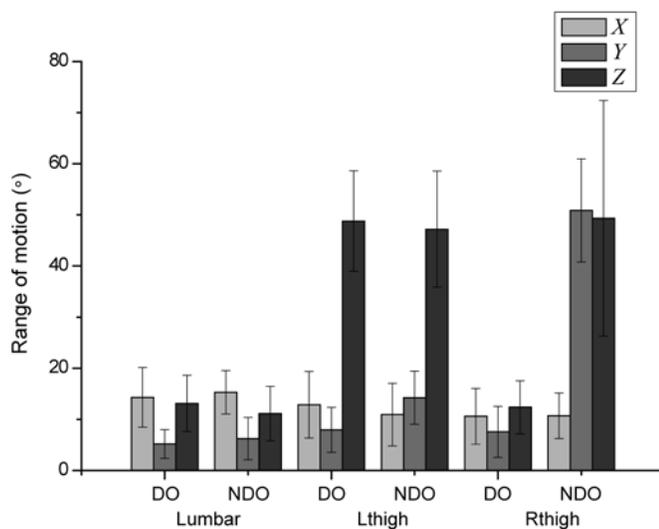
Table 2.

Results of repeated measures analysis of variance for each spinal region (lumbar and right and left hip joints) and plane (X, Y, and Z).

Effect	Mean Square	F-Value	p-Value
Region	55.52	0.72	0.40
Dominance	21,153.28	198.83	0.001*
Region × Dominance	1,019.19	14.21	0.001*
Region × Dimension	306.35	3.12	0.08
Dominance × Dimension	8,646.72	141.08	0.001*
Region × Dominance × Dimension	2,475.38	26.30	0.001*

* $p < 0.01$.

Dimension = X, Y, and Z planes; Dominance = axial rotation to dominant and nondominant directions; Region = lumbar and bilateral hip joints.

**Figure 2.**

Three-dimensional spinal range of motion (ROM) differences for axial rotation to dominant (DO) and nondominant (NDO) directions. Spinal ROM was significantly different between dominance ($F = 198.83$, $p = 0.001$), region × dominance ($F = 14.21$, $p = 0.001$), and dominance × dimension ($F = 141.08$, $p = 0.001$). A three-way interaction was found between region, dominance, and dimension ($F = 26.30$, $p = 0.001$) (X = frontal, Y = sagittal, Z = transverse planes). Error bars indicate standard deviation from mean. L = left, R = right.

stability in the pelvic and lumbar spine regions as well as the hip joints [29–31]. For example, participants with LBP were able to manage the lifting activity by increasing lumbar and hip movements in the frontal and horizontal planes of motion while limiting movements in the sagittal plane [31]. However, no specific kinematic measure existed for the differences between the lumbar spine and hips during axial trunk rotation while the lower-limb

side of dominance was considered. Therefore, we conducted our study to clarify the combined effects between side of dominance and 3-D kinematic motions.

The results of our study indicated that spinal ROM was significantly different based on region × dominance as well as between dominance × dimension. In addition, a three-way interaction was found between region, dominance, and dimension. Some variability was expected to exist between and within participants; however, a significant difference was found in rotational displacement of the transverse and sagittal axes, which significantly increased when the participants attempted to rotate, especially on the nondominant hip. In addition, a three-way interaction was found between body region, dimension, and age.

The combined effect of decreased axial trunk ROM on the dominant hip might stiffen passive structures of the hip joint because of increasing age. The functions of the lumbar spine and hip joints might be altered based on the stiffened side of dominance of the hip joint. This stiffened functional motion is important to examine for one to understand compensatory mechanisms in addition to poor proprioception in participants with LBP. Overall, this finding suggests that decreased ROM for the lumbar spine and both hips might limit the coordination of postural adjustability, especially on the dominant side [32–33]. This uncoordinated axial rotation of the trunk might be a risk of spinal injuries during twisting activities.

Although we did not measure activities of electromyography during trunk rotation, a relationship between hip muscle activities that occur in response to lumbar stiffness could be investigated. To maintain postural stability during axial trunk rotation activities within a certain functional ROM, 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 kinematic analyses during axial trunk rotation could be affected by proprioceptive deficits as well as postural balance and neuromuscular performance [34–35]. The results of our study indicated that 3-D kinematic data of spinal ROM were significantly different for the dominant side as well as the lumbar spine. A three-way interaction was found between region, dominance, and dimension during axial trunk rotation regardless of age.

Spinal ROM might be affected by increased stiffness because of a repeated pattern of movements as Janda reported [36]. These results exemplify the need to investigate

further the lumbar and hip regions based on 3-D analysis, while considering the dominance effect for trunk rotational displacement. Several studies provided a concept of regional interdependence and a detailed overview of the evidence supporting the potential interactions between the lumbar spine and hip joints [37–38]. The early detection of stiffened hip joints and overall spinal flexibility could be important in understanding compensatory mechanisms and preventing back injuries.

In addition, age was clinically relevant when we evaluated different compensatory responses during trunk movements [39–40]. Our results also support the decrease in transverse axis displacement, especially in older persons. In a recent review, impaired balance, poor muscle strength, visual impairment, impaired gait, and activities of daily living limitations have consistently been found to increase the risk of postural problems in older persons [41–42]. Therefore, one should understand the potential benefit of dominant hip joint flexibility strategies based on pathomechanical spinal movement patterns. During axial rotation, the ROM of the dominant hip joint might be limited; however, our study did not examine the cause and effect relationship. These motion patterns might be assumed to be functional compensation strategies following altered neuromuscular coordination, which might be the consequence of an imprecise internal estimate of compensation because of reduced accuracy in the sensory integration process.

One limitation of this study was the selection of the group, which included “volunteers.” Increasing the number of participants would increase the power of the study. Another limitation was that the individual participants might vary even within a nondisabled population. The variability between the results of the dominant and non-dominant lower limbs might not be significant since no significant change was found in the axial trunk rotation test. Quantifying inter- and intraparticipant variability with subgroup analyses would be beneficial, which can validate the test.

Despite these limitations, a number of populations, including nondisabled participants, value the quantification of dominant hip motion deficits. This study particularly interests the clinician who commonly evaluates the hip and lumbar spine and assesses patient progress in the rehabilitation setting. The lack of motion of the dominant hip joint in the transverse and sagittal axes might be related to the flexibility of the whole spinal region. A participant with a stiffened back might demonstrate

decreased hip joint flexibility in addition to poor proprioception from back injuries to passive structures. Follow-up randomized, controlled trials are needed for investigating the characteristics of hip joint flexibility and adjustability as well as spinal compensation strategies for enhancing both biomechanical and neuromuscular aspects of age differences.

CONCLUSIONS

Our study demonstrated that spinal ROM was significantly different for the dominance, region, and hip motion. The results of a three-way interaction between region, dominance, and dimension indicated that a significant difference existed in the rotational displacement of the transverse and sagittal axes, which significantly increased when the participants attempted to rotate, especially on the dominant hip. Decreased axial trunk ROM on the dominant hip was related to stiffened passive structures of the hip joint. The functions of the hip joints and lumbar spine might be altered based on the stiffened dominant hip joint, although some variability exists between and within participants.

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Author Contributions:

Study concept and design: P. S. Sung, Y. H. Kim.

Acquisition of data: P. S. Sung.

Analysis and interpretation of data: P. S. Sung.

Drafting of manuscript: P. S. Sung.

Critical revision of manuscript for important intellectual content: P. S. Sung.

Statistical analysis: P. S. Sung.

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Administrative, technical, or material support: Y. H. Kim.

Study supervision: P. S. Sung, Y. H. Kim.

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Participant Follow-Up: The authors do not plan to inform participants of the publication of this study. However, participants have been encouraged to check the study Web site for updated publications.

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