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A kinematic and kinetic analysis of spinal region in subjects with and without recurrent low back pain during one leg standing

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ABSTRACT

Background: The purpose of this study was to evaluate the relationship between normalized kinematic and kinetic stability indices for spinal regions with eyes-open and eyes-closed conditions during non-dominant leg standing between subjects with recurrent low back pain and control subjects.
Methods: The kinematic stability index for the spinal regions (core spine model, lumbar spine, lower and upper thorax) and the kinetic stability index from force plate were measured. All participants were asked to maintain non-dominant leg standing with the dominant hip and knee flexed approximately 90 degrees for 25 seconds. Forty-two participants enrolled in the study, including 22 subjects with low back pain (12 male, 10 female) and 20 control subjects (12 male, 8 female).
Findings: For the kinematic index for stability, the visual condition ($F = 30.06$, $p = 0.0001$) and spinal region ($F = 10.82$, $p = 0.002$) were statistically significant. The post hoc test results indicated a significant difference in the lumbar spine compared with the upper and lower thorax and the core spine model. The kinetic stability (average [standard deviation]) during the eyes-closed condition significantly decreased in the low back pain group ($t = -3.24$, $p = 0.002$).
Interpretation: The subjects with recurrent low back pain demonstrated higher lumbar spine stability in eyes-open condition. This higher stability of the lumbar spine might be due to a possible pain avoiding strategy from the standing limb. The low back pain group also significantly decreased kinetic stability during the eyes-closed condition. Clinicians need to consider both kinetic and kinematic indices while considering visual condition for lumbar spine stability in subjects with recurrent low back pain.

1. Introduction

Recurrent low back pain (LBP) is a common musculoskeletal dysfunction in our society (van Tulder et al., 2006). There is a 24% to 87% rate of recurrence within one year in those who have recovered from an episode of LBP (Pengel et al., 2003; Stanton et al., 2008). Several studies have reported poor coordination of balance performance in subjects with recurrent LBP (Brumagne et al., 2000; Sung and Park, 2009; Tsao et al., 2010). It is generally accepted that individuals with recurrent LBP possess altered proprioceptive postural control as well as less refined positional sense (Brumagne et al., 2008b; Tsao and Hodges, 2008; Sung, 2013). However, there is a lack of understanding on altered kinematic and kinetic coordination during one leg standing in subjects with recurrent LBP.

Kinematic and kinetic analyses of various tasks have been extensively investigated in subjects with LBP (Sung et al., 2010; Lee et al., 2012). These analyses are clinically important to enhance evidence-based practice and to compare outcomes by integrating the best quantitative evidence. Therefore, the kinematic pattern of spinal region as well as kinetic information from force plate data during one leg standing should be carefully investigated in subjects with recurrent LBP and controls.

Previously, the displacement angles of the specific spinal regions were calculated between two adjacent joints and compared with the stability index (Sung et al., 2010; Jo et al., 2011). Other studies also emphasized the interaction between the spine and lower extremities when trying to understand balance strategies (McGregor and Hukins, 2009; Sung and Ham, 2010; Sung and Kim, 2011). These studies reported valuable findings for movement patterns and range of motion (ROM); however, the data need to be compared with normalized kinematic and kinetic differences between groups.

Several studies also compared a single-leg hop for the differences in kinematics and reported a significant risk of knee injuries with preponderance in the non-dominant leg (van der Harst et al., 2007; Krajnc et al., 2010). The maintenance of balance is influenced by a range of several sensorimotor functions, including muscular strength, proprioception, and the visual and vestibular sensory systems (Brumagne et al., 2008a; Treleaven, 2008; Vaugoyeau et al., 2008). Our preliminary data

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also indicated that non-dominant leg standing is sensitive to the specific task when investigating dynamic balance. These studies indicated that postural controls need to be harmonized by coordination and integration of the somatosensory and vestibular systems as well as visual condition (Massion, 1992), especially during non-dominant leg standing.

The kinematic stability has frequently been used for balance assessments based on the ground reaction force and muscle activities (Lee et al., 2007; Sung and Park, 2009; Burnett et al., 2011). The performance of postural stability reflects kinematic changes during standing (Karlsson and Frykberg, 2000), and the possible postural stability might be due to proprioceptive deficits in the spinal region (Nies and Sinnott, 1991; Silfies et al., 2003; Jo et al., 2011). However, most studies did not investigate both kinematic and kinetic indices for analysis of the spinal region, which was defined with the core spine model, lumbar spine, and lower and upper thorax in our study.

The core spine model, as in our previous study, was used as a reference model for motion analysis to compare specific three-dimensional kinematic data and to differentiate with motion of the lumbar spine, which is directly articulated between the pelvis and the thorax (Lee et al., 2012). A lack of kinematic and kinetic coordination of the lumbar spine may cause musculoskeletal injuries, especially with sudden perturbation (Henry et al., 2006; Sung and Park, 2009). In addition, the altered coordination within the postural reaction might lead to compensatory responses to prevent injuries (Shum et al., 2005, 2007; Sung et al., 2010).

Clinicians need to understand postural compensation strategies based on lumbar and core spine motions in order to adjust balance on the ground as well as position-dependent spinal loading for rehabilitation strategies. The postural compensation may lead to a better understanding of spinal movement patterns to clarify the relationship between kinematic and kinetic changes in eyes-open and eyes-closed conditions in subjects with recurrent LBP.

Therefore, the purpose of this study was to investigate differences in normalized kinematic and kinetic stability changes on spinal regions while considering visual condition during non-dominant leg standing between subjects with recurrent LBP and control subjects.

2. Methods

2.1. Target population

Subjects were recruited from the University community, and those subjects who met study inclusion criteria received information regarding the study and signed a copy of the Institutional Review Board approved consent form (IRB#8-15B). Subjects with recurrent LBP were eligible to participate if they: 1) were 25 years of age or older, 2) reported at least one episode of LBP in the past two years, 3) had no current episode of pain referral into the upper/lower extremities at least one month prior to the data collection, 4) had no structural dysfunction of the spine or lower extremities at the time of data collection, and 5) had no acute pain primarily of muscular origin, which was determined by the subjects' orthopedic surgeons. The dysfunction was defined as a disturbing impairment or abnormality of function (Sung, 2003).

Subjects with recurrent LBP were excluded from participation 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), 3) had a structural spinal problem, and/or 4) were pregnant. Participants were withdrawn from the study if they requested to withdraw.

The control subjects were recruited based on similar individual characteristics as the subjects with LBP. The lower extremity dominance was also applied in this study since the previous study confirmed that dominance could be a confounding factor (Sung et al., 2004). The right lower extremity was regarded as the dominant side for all subjects since they preferred to use the right limb to kick a ball (Andersen et al., 2004; Brophy et al., 2010). The non-dominant side was selected for the analysis from previous studies (Sung et al., 2004; Lee et al., 2012).

2.2. Outcome measures

The level of dysfunction of all participants was evaluated by the Oswestry Disability Index (ODI), which is one of the most frequently used tools for measuring chronic disability (Ciccone et al., 1996). A sum is calculated and presented as a percentage, where 0% represents no disability and 100% the worst possible disability (Fairbank and Pynsent, 2000).

The effect of visual condition was investigated by having subjects open or close their eyes during the test. All participants performed three trials with their eyes-open and with their eyes-closed during non-dominant leg standing. The initial position was standing relaxed with eyes open and weight evenly distributed between both feet. The subjects were then instructed to stand freely on the non-dominant leg with the dominant hip and knee flexed approximately 90 degrees. They were allowed to practice three times before testing, and three trials of the task were performed for consistency. The average values for measurements were utilized for the data analysis. Subjects kept their arms along the sides of the trunk during initial standing and task performance. The compensatory arm movements were allowed.

The subjects had the modified Helen Hayes full trunk (with head) reflective marker set attached to specific sites on their bodies with adhesive tape rings (Schache et al., 2008; Buczek et al., 2010; Sung et al., 2010). The kinematic data were recorded and processed by six digital cameras capturing full kinematic motions sampling at 120 Hz. The balance changes imposed during non-dominant leg standing were measured and the recordings lasted 25 seconds. The duration was determined according to our preliminary study and by considering the Carpenter et al. study, which collected data for 20 seconds for two-leg stance and one-leg stance tasks (Allum et al., 2001; Gill et al., 2001).

The motion analysis (Motion Analysis Corporation, Santa Rosa, CA) with six infrared cameras was used to determine the thorax, lumbar spine, and other joint angular kinematics during the test. The reflective markers were attached bilaterally to the following anatomic landmarks: heel, second metatarsal head, lateral and medial malleoli, tibial tuberosity, lateral and medial knee joints, anterior superior iliac spine (ASIS), posterior superior iliac spine, and greater trochanter as well as the second sacral process (S2). For the shoulders, markers were placed over the acromio clavicular joints, lateral humeral epicondyles, proximal and distal radioulnar joints, and front of head, rear of head, top of head, and inferior angles of the scapulae as well as the 7th cervical vertebra spinous process (C7), mid manubrium sterni, radial styloid process, and hands.

In Fig. 1, the angular displacement of the kinematic data was calculated. For example, the lumbar rotation segment was defined by a vector from a marker superficial to the S2 to a marker superficial to the first lumbar process (L1); the lower thoracic region was defined by a vector from the L1 marker to a marker superficial to the sixth thoracic spinous process (T6); the upper thoracic region segment was defined by a vector from the T6 marker to a marker superficial to C7. Each marker position was calculated relative to the coordinate system of the pelvis. The pelvic coordinate system was defined, and the origin was at the S2 marker. The ASIS marker defined the x-y plane of the pelvis, and the positive z-axis was defined by a vector perpendicular to the x-y plane. Marker trajectories were low pass filtered (6 Hz, 4th order Butterworth filter) and then time synchronized within the test cycle into Matlab R2010b (The MathWorks, Inc. Natick, MA).

A Cartesian axis system was utilized for body regions, with the X-axis running left to right and parallel to a line between the two upper markers. The Z-axis was running caudal to rostral and parallel to a line between the caudal marker and the mid-point between the two rostral markers, and the Y-axis was running from posterior to anterior and defined by the cross product of the Z- and X-axes (Preuss and Popovic, 2009).