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The effect of three-dimensional postural change on shear elastic modulus of the iliotibial band

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ABSTRACT

To understand and treat iliotibial band (ITB) syndrome, caused by excessive compression between the ITB and lateral femoral condyle, it is important to identify factors contributing to an increase in ITB stiffness. The purpose of this study was to clarify the factors that contribute to an increase in ITB stiffness by examining the relationship between three-dimensional postural changes and ITB stiffness. Fourteen healthy individuals performed one-leg standing under 7 conditions (including normal one-leg standing as a control condition) in which the pelvic position was changed in three planes. The shear elastic modulus in the ITB was measured using shear-wave elastography, as a measure of ITB stiffness. The three-dimensional joint angles and external joint moments in the hip and knee joints were also measured to confirm the changes in joint angles and external load. Compared to the normal one-leg standing condition, ITB stiffness was significantly increased in the pelvic posterior tilted position (i.e. hip extension), contralateral pelvic dropped position (i.e. hip adduction), and contralateral pelvic posterior rotated position (i.e. hip external rotation). The findings suggest that interventions to reduce hip extension, adduction, and external rotation might be useful if these excessive positional changes are detected in patients with ITB syndrome.

1. Introduction

Iliotibial band (ITB) syndrome, which causes pain in the lateral aspect of the knee, occurs in 5–14% of runners (van der Worp et al., 2012), and frequently occurs in patients with knee osteoarthritis (Vasilevska et al., 2009). The excessive compression between the ITB and the lateral femoral epicondyle has been proposed as a cause of ITB syndrome (Fairclough et al., 2007). Excessive stiffness of the ITB can increase the compression force exerted by the ITB on the lateral femoral epicondyle; therefore, investigation of the factors that increase ITB stiffness can improve our understanding of ITB syndrome.

The ITB is a lateral thickening of the fascia in the thigh, connecting the hip and knee muscles (i.e., the gluteus maximus, gluteus medius, tensor fasciae latae [TFL], and vastus lateralis), lateral intermuscular septum, lateral femoral epicondyle, patella, and tibia (Terry et al., 1986; Vieira et al., 2007; Becker et al., 2010). Consequently, ITB stiffness could be influenced by factors such as joint angles, external joint moments, and corresponding muscle tension during movement.

Several studies have found kinematic changes at the hip and knee joints in patients with ITB syndrome, which may contribute to this pathology, though a specific cause-and-effect relationship is not well-defined (Miller et al., 2007; Noehren et al., 2007; Hamill et al., 2008; Feber et al., 2010; Foch and Milner, 2014; Louw and Deary, 2014). A prospective study found greater hip adduction and knee internal rotation throughout the stance phase of running in patients with ITB syndrome (Noehren et al., 2007). These authors presumed that excessive hip adduction and knee internal rotation increases ITB strain, causing the ITB to compress against the lateral femoral condyle. Research using a musculoskeletal model has reported that increasing step width during running reduces ITB strain and the strain rates mediated by decreased hip adduction (Meardon et al., 2012). These findings strongly suggest that kinematic changes, especially in hip motion in the frontal plane, significantly influence ITB stiffness.

Furthermore, in planes other than the frontal plane, Noehren et al. (2007) found that individuals who develop ITB syndrome exhibited greater external rotation of the femur. In addition, it

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was reported that female runners with ITB syndrome exhibited greater hip external rotation while running than male runners with ITB syndrome and healthy female runners (Phinyomark et al., 2015). In a cadaver-based study, strain in the ITB was greater during hip flexion and adduction stretching, which increase the tensioning role of the gluteus maximus more than a straight leg raise; however, no difference was found in ITB strain between the hip flexion and adduction stretching and the modified Ober test, which includes hip extension and adduction (Falvey et al., 2010). These findings demonstrate the importance of focusing on hip joint motion changes in the sagittal and transverse planes in addition to the frontal plane, as these factors may contribute to increased ITB stiffness. However, the anatomical complexity of the ITB makes it difficult to estimate the ITB stiffness by observing joint motion. The factors contributing to an increase in ITB stiffness would be revealed by comparing in vivo measurements of ITB stiffness following posture changes.

Shear-wave elastography (SWE) is a reliable, non-invasive ultrasonographic imaging technique for evaluating elasticity of soft tissue by measuring the propagation velocity of the shear waves in the tissues, enabling the calculation of the shear elastic modulus (Kot et al., 2012; Maïsetti et al., 2012; Aubry et al., 2013; Eby et al., 2013). SWE has been used for measuring stiffness of the soft tissue such as muscle and tendon (Aubry et al., 2013, 2015; Brandenburg et al., 2014). Recently, we have demonstrated that, compared to normal one-leg standing, an increased hip adduction angle and adduction moment at the hip and knee joints leads to an approximately 32% increase in ITB stiffness, measured in vivo using SWE (Tateuchi et al., 2015). However, the in vivo measurement of ITB stiffness has only been performed in our two-dimensional investigation (Tateuchi et al., 2015); the effect of postural changes on ITB stiffness is poorly understood. Therefore, the purpose of this study was to clarify the factors contributing to an increase in ITB stiffness using quantitative SWE by examining the relationship between three-dimensional postural changes and ITB stiffness. Based on the previous related research (Noehren et al., 2007; Falvey et al., 2010; Phinyomark et al., 2015), we hypothesized that ITB stiffness would be increased in the (1) hip adducted position in the frontal plane, (2) hip externally rotated position in the transverse plane, and (3) hip flexed position in the sagittal plane compared to the normal one-leg standing position.

2. Methods

2.1. Participants

Fourteen healthy volunteers (7 men and 7 women; age, 22.0 ± 1.0 (mean ± SD) years; weight, 61.3 ± 11.5 kg; height, 168.6 ± 7.9 cm) were recruited from the local student population. The exclusion criteria included the presence of disease of any joint in the lower extremity or spine, neurological disease, or a history of ITB syndrome. All subjects provided informed consent and the study received ethical approval from the local ethical committee.

2.2. Experimental protocol

Prior to the one-leg standing condition, kinematic data were collected for 5 s in the bilateral standing position, which were used as a reference for calculating the joint angles. We then manipulated the pelvic rotational position while the participant maintained a stable one-leg standing position, to vary the three-dimensional hip joint angles. The pelvic rotational position is a point of observation during the retraining of running gait in patients with ITB syndrome (Hunter et al., 2014), as it is directly related to hip joint motion. One-leg standing was performed on the dominant leg, defined as the leg that the participant would use to kick a ball. Trials under the 7 one-leg standing conditions were conducted as follows (Fig. 1): normal condition (NO), normal one-leg standing with no pelvic and trunk inclination; PT, 10° posterior tilt of the pelvis (i.e. hip extension); AT, 10° anterior tilt of the pelvis (i.e. hip flexion); CD, 10° drop of the pelvic contralateral side (i.e. hip adduction); CR, 10° rise of the pelvic contralateral side (i.e. hip abduction); PR, 5° posterior rotation of the pelvic contralateral side (i.e. hip external rotation); and AR, 10° anterior rotation of the pelvic contralateral side (i.e. hip internal rotation). The pelvic rotation angle was set at 5° in the PR condition because a stable posture could not be maintained at 10°. In the PT, AT, CD, and CR conditions, inclination of the trunk in the same direction as pelvic rotation was allowed to maintain balance. The pelvic angle change was verified by an examiner using a goniometer before each data collection. The contralateral hand was held at the abdomen. To maintain a stable posture, the participant was allowed to touch a fixed device with an index fingertip, which minimized mechanical support. The order of the 7 conditions was randomized. ITB stiffness was measured using SWE after holding each stable posture for 5 s, based on a previous study (Kot et al., 2012). The kinematic and kinetic variables were recorded synchronously for 3 s while maintaining each posture, following the SWE measurement.

2.3. Shear-wave elastography

ITB stiffness was measured at the level of the superior border of the patella using SWE (Aixplorer, SuperSonic Imagine, Aix-en-Provence, France) while the participant maintained each posture. Prior to the measurements, the investigator identified the ITB at the level of the superior border of the patella by palpation and examination of the B-mode image, which is two dimensional brightness mode ultrasonography, and marked the measurement site and the anterior and posterior borders of the ITB with a pen (Fig. 2a). The transducer was placed lightly on the participant using a generous amount of ultrasound gel. A single investigator performed all SWE measurements. In the present study, the transducer was placed transversely because the shear elastic modulus of the calcaneal tendon was increased in response to tendon stretching regardless of whether the measurements are made longitudinally or transversely, and the reproducibility of the longitudinal measurement tended to be decreased in a tendon stretched position because it reaches the upper limit of the measurement device (Aubry et al., 2013, 2015). Therefore, we utilized transverse measurements of the ITB, which is regarded as a tendinous tissue (Fairclough et al., 2006).

Based on the thickness (approximately 1.9 mm) and width (approximately 5.3 mm) of the ITB determined using ultrasonography (Goh et al., 2003; Wang et al., 2008), regions of interest (ROIs) with a diameter of 1.5 mm were set in the ITB. Although elastic modulus value is not influenced by the ROI's size when the mean value in the ROI is used (Kot et al., 2012), the ROI's size in our study was considerably smaller, approximately half the size of that in the previous study in the calcaneal tendon (Aubry et al., 2013). Therefore, the 3 ROIs were set horizontally to cover the entire region of the ITB although only one ROI was commonly used in the previous study using SWE, while the mean value of the 3 ROIs was used to determine a more representative measure (Fig. 2b). Based on the local shear wave propagation velocity, c, the Young's modulus, E, was calculated from $E = 3\rho c^2$ where density ρ is assumed to be constant (1000 kg/m^3) (Aubry et al., 2013). The observed values of Young's modulus were divided by 3 to obtain the shear elastic modulus. All measurements were performed twice and the mean shear elastic modulus values for 2 trials were used in the analysis. The determination of the ROI and calculation of the shear elastic