Gait & Posture 43 (2016) 120–124

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length Article

Sagittal plane pelvis motion influences transverse plane motion of the femur: Kinematic coupling at the hip joint

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ARTICLE INFO

Article history:
Received 10 May 2015
Received in revised form 31 August 2015
Accepted 14 September 2015

Keywords:
Kinematic coupling
Hip
Femur rotation
Pelvis tilt

ABSTRACT

Previous studies have suggested that internal femur rotation can influence sagittal pelvis motion. This indicates that there may be kinematic "coupling" of these two segments. The purpose of the current study was to determine whether there is a consistent and predictable kinematic relationship between the pelvis and the femur. Sixteen healthy subjects (nine females, seven males) performed three trials of maximum anterior and posterior pelvis tilt at four different hip flexion angles (0°, 30°, 60°, and 90°). Ordinary least squares regressions were used to calculate the ratio of transverse femur motion to sagittal pelvis motion using the mean kinematic curves during maximum anterior and posterior pelvis tilting. R^2 values were used to assess the strength of the kinematic relationship between these segments at each hip flexion angle. The ratios of transverse femur motion to sagittal pelvis motion were consistent across all hip flexion angles during anterior and posterior pelvis tilting (range 0.23–0.32; R^2 values greater than 0.97). On average, for every 5° of anterior pelvis tilt there was 1.2–1.6° of internal femur rotation and the converse was true for posterior pelvis tilt and external femur rotation. Our findings suggest that altered pelvis movement in the sagittal plane may influence transverse femur motion. The observed coupling behavior between the pelvis and femur may have implications for musculoskeletal conditions in which excessive internal femur rotation has been deemed contributory to symptoms (i.e. femoroacetabular impingement).

1. Introduction

The hip joint is a complex anatomical structure comprised of the pelvis and the femur. The inherent stability of the hip occurs secondary to the ball and socket bony morphology, the thick capsule and ligaments [1,2], and the strong muscles surrounding the joint [1]. As a result of the highly congruent nature of this joint and the closely approximated joint surfaces [1,3] it is likely that movement of one segment may influence the other.

Previous studies have suggested a potential relationship between transverse plane femur and sagittal plane pelvis motions [4–7]. Duval et al. [4] reported that internal rotation of the lower extremity during standing resulted in an anterior pelvis tilt and external rotation of the lower extremity resulted in a posterior pelvis tilt. These authors proposed that this kinematic relationship occurred as a direct result of bony approximation between the femoral head and the acetabulum [4]. Further support for kinematic coupling between the pelvis and the femur comes from studies in which calcaneal wedging was used to induce foot pronation [5–7]. These studies revealed that calcaneal eversion resulted in internal tibia rotation, internal femur rotation, and anterior pelvis tilting [5–7]. The kinematic relationship between the pelvis and femur has been shown to exist during bilateral [5,6] and unilateral standing [6,7].

The fact that transverse plane motion of the femur can influence sagittal plane motion of the pelvis is suggestive of kinematic coupling between these two segments. Coupling arises when a force or torque in one direction causes motion in another direction [8]. At the foot–ankle complex, for example, there is a well-studied relationship between calcaneal eversion and internal tibia rotation [9,10]. In the cervical spine, axial rotation has been shown to be coupled with ipsilateral lateral flexion [11,12]. While previous research supports the premise that internal femur rotation contributes to anterior pelvis tilt [4–7], it is not clear if the same

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http://dx.doi.org/10.1016/j.gaitpost.2015.09.010
0966-6362/

coupling relationship occurs reciprocally (i.e. whether sagittal plane pelvis motion influences transverse plane femur motion). Additionally, research in this area has focused on upright standing postures [4–7], so it is not known if the same coupling behavior exists at greater hip flexion angles similar to those that occur during functional tasks.

The purpose of the current study was to systematically explore whether there is a consistent and predictable kinematic relationship between sagittal plane motion of the pelvis and transverse plane motion of the femur during anterior and posterior pelvis tilting. It was hypothesized that sagittal plane pelvis motion and transverse plane femur motion would be significantly correlated at various hip flexion angles. It also was hypothesized that the ratio between transverse femur motion and sagittal pelvis motion would be similar between anterior and posterior pelvis tilting. The presence of kinematic coupling at the hip joint may have implications for musculoskeletal conditions in which internal femur rotation has been shown to be contributory to pathology (i.e. femoroacetabular impingement).

2. Methods

2.1. Participants

Sixteen subjects consisting of 9 females (28.0 ± 7.6 years; 60.8 ± 7.5 kg; 164.6 ± 5.2 cm) and 7 males; (29.3 ± 4.8 years; 76.1 ± 10.4 kg; 178.0 ± 4.7 cm) participated in this study. Participants had no history of hip pain, no previous hip surgery, and no complaints of lower extremity or low back pain during the preceding 6 months. Data collection occurred in the Jacquelin Perry Musculoskeletal Biomechanics Research Laboratory at the University of Southern California. Prior to participation, all subjects were informed of the purpose of the study and provided written informed consent.

2.2. Procedures

Three-dimensional kinematics were collected at 250 Hz using an 11-camera Qualisys motion analysis system (Qualisys AB, Göteborg, Sweden). Reflective markers (11 mm diameter) were placed on the most distal aspect of the second toes, the first and fifth metatarsal heads, the medial and lateral malleoli, the medial and lateral femoral epicondyles, the greater trochanters, the iliac crests, and the L5–S1 junction. Semi-rigid plastic plates with mounted tracking markers were secured to the heels, shanks, and thighs (Fig. 1). Prior to data collection, a standing calibration trial was collected to determine the segmental coordinate systems and the joint centers. All markers were then removed with the exception of the semi-rigid clusters and the markers on the iliac crests, and the L5–S1.

Subjects were instructed to stand upright with the feet *stationary*, shoulder width apart, toes pointing forward with shoulders flexed to 90°. Participants then performed a maximum anterior and posterior pelvis tilt without moving at the trunk or flexing the knees. Subjects practiced this motion at a set pace of 20 beats-per-minute in each direction (maximum anterior pelvis tilt to maximum posterior pelvis tilt) until they were comfortable with the task. Approximately 5 to 15 practice trials were performed.

Following familiarization with the movement, five continuous repetitions of this task were performed. Subjects then performed a bilateral squat to 30° of hip flexion as determined using a goniometer. Starting from this position, subjects again performed five repetitions of maximum anterior and posterior tilt of the pelvis at the same pace described above. This task subsequently was performed at hip flexion angles of 60° and 90° (Fig. 2). All subjects were able to successfully perform the desired pelvis motions for all knee flexion conditions.

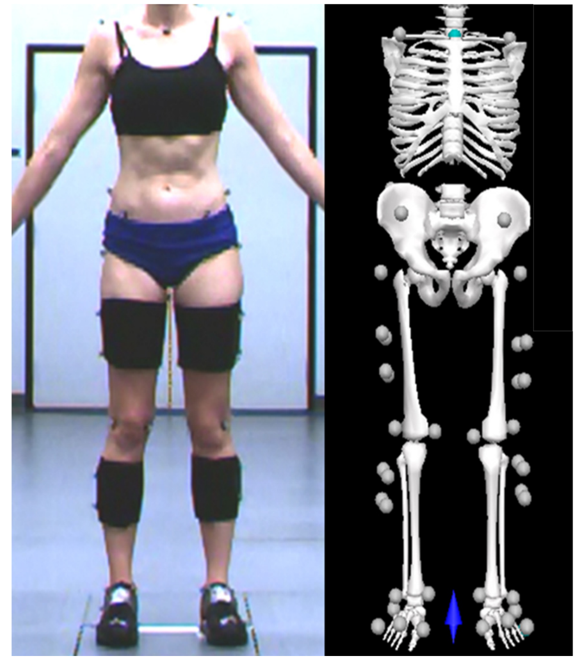

Fig. 1. Marker set utilized for static trial.

2.3. Data analysis

Three-dimensional kinematic data were processed with Visual 3D software (C-motion, Inc., Germantown, MD). Kinematic data were low-pass filtered at 6 Hz using a 4th-order Butterworth filter. The middle three repetitions at each hip flexion angle for each subject were averaged. The femur and pelvis angles were calculated as the orientation of the femur and pelvis segments relative to the global coordinate system. The average of the three repetitions for each hip flexion angle was calculated from the individual participant's data. The individual means for the 16 participants were then averaged at each hip flexion angle to create the average angle–angle plot.

2.4. Statistical analysis

The ratio of femur transverse motion to pelvis sagittal motion was calculated at each hip flexion angle as the unstandardized coefficient of the linear regression of the average data during the period of anterior pelvis tilt and during the period of posterior pelvis tilt using PASW software (SPSS, Inc., Chicago, IL). This provided an estimate of the change in femur transverse rotation per degree of pelvis sagittal tilt. The R^2 value for the mean femur transverse angles and the mean pelvis sagittal angles throughout this motion also was calculated for each hip flexion angle.

3. Results

All kinematic variables of interest demonstrated acceptable normality with skewedness and kurtosis values less than ±0.5 and ±2, respectively. Mean transverse plane femur excursions during the 0°, 30°, 60°, and 90° hip flexion angle conditions were 7.4 ± 4.3°, 7.0 ± 5.5°, 5.6 ± 4.2°, and 5.3 ± 2.8°, respectively. Mean sagittal plane pelvis excursions during the 0°, 30°, 60°, and 90° hip flexion angle conditions were 23.4 ± 7.5°, 20.8 ± 12.2°, 20.3 ± 11.9°, and 16.6 ± 8.9°, respectively. The average femur transverse motion to