Full length Article

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

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A B S T R A C T

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. R² 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; R² 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 pelvis rotation has been deemed contributory to symptoms (i.e. femoroacetabular impingement).

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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 pelvic 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...
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 Jacqueline 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 kinematic data 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.

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 R² 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 skewness 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
pelvis sagittal motion ratios ranged from 0.23 to 0.32 and from 0.25 to 0.31 for anterior and posterior tilting, respectively (Table 1 and Figs. 3 and 4). The $R^2$ values between femur transverse and pelvis sagittal motion indicated a strong, linear relationship at each hip flexion angle tested ($R^2$ values of 0.97 or greater; Figs. 3 and 4).

4. Discussion

A consistent pattern of kinematic coupling of anterior pelvis tilt and internal femur rotation (and, conversely, posterior pelvis tilt and external femur rotation) was observed at each hip flexion angle evaluated. All 16 participants demonstrated this coupling behavior at the 0° hip flexion condition, and 15 out of the 16 participants demonstrated the coupling behavior in the 30°, 60°, and 90° hip flexion conditions. When averaged across all hip flexion angles, there was 1.2–1.6° of internal femur rotation for every 5° of anterior pelvis tilt. Similarly, there was 1.2–1.6° of external femur rotation for every 5° of posterior pelvis tilt. This relationship was consistent across hip flexion angles and during periods of both anterior and posterior tilt, suggesting that kinematic coupling between these segments is robust.

Our findings confirm and expand upon previous reports of kinematic coupling between the femur and the pelvis [4–7]. Consistent with the current study, Duval et al. [4] found a significant relationship between internal femur rotation and anterior pelvis tilt. Contrary to the findings of the current study, however, these authors reported that the relationship between external femur rotation and posterior pelvis tilt was less pronounced than that between internal femur rotation and anterior pelvis tilt [4]. The findings of the current study reveal that coupling was nearly identical during anterior pelvis tilting and posterior pelvis tilting.

To the best of our knowledge, this is the first study to demonstrate that motion of the pelvis in the sagittal plane can influence motion of the femur in the transverse plane. While it is beyond the scope of this paper to explain the mechanism underlying the observed coupling, several possibilities exist. Motion at any joint is heavily influenced by bony anatomy. The hip joint, in particular, is highly congruent with closely approximated joint surfaces [1,3] secondary to its thick capsule [1,2], strong musculature [1], and the negative pressure within the joint space [13]. As such, it is logical that motion of one segment would have a predictable influence on the other. Many highly congruent joints exhibit kinematic coupling. For example, the relationship at the foot–ankle complex between calcaneal eversion and tibial internal rotation has been well documented [9,10].
Duval et al. [4] suggested that internal rotation of the femur causes the femoral head to rotate posteriorly into the posterior acetabulum which pushes the pelvis into an anterior tilt. Conversely, it is possible that anterior tilt of the pelvis rotates the acetabulum ante-riror-inferiorly into the anterior femoral head, which pushes the femur into internal rotation. Other factors, such as muscle activation, soft tissue length, and bony alignment (i.e. femoral or acetabular version or inclination) also may influence intersegmental coupling [4].

Understanding contributory factors to hip joint motion is important in populations where abnormal kinematics have been implicated. In persons with femoroacetabular impingement, for example, anterior pelvis tilt and femur internal rotation increase approximation of the femoral head-neck junction with the acetabulum [14,15]. Such abutment is hypothesized to contribute to labral damage [16–18], chondral damage [16,17,19], and hip osteoarthritis [20,21]. Additionally, kinematic studies have identified differences in sagittal [22–25] and transverse plane hip and pelvis kinematics [23,25] between persons with and without femoroacetabular impingement. Our findings indicate that altered sagittal plane pelvis kinematics in persons with femoroacetabular impingement may influence hip rotation.

There are certain limitations of this study that should be considered when interpreting the results. Skin markers were used to assess segment position and may have been subject to soft tissue movement artifact. Marker artifact error was minimized however through use of thigh clusters comprised of four markers [26], and the fact that we studied of a relatively slow movement with minimal inertial effects [27]. Another limitation is that only isolated intentional motion of the pelvis was examined. The ratio of femur to pelvis motion may vary during more dynamic tasks that involve greater excursions and muscular demands. The ratio between femur rotation and pelvis tilt also may differ between weightbearing and non-weightbearing tasks. Furthermore, the coupling behavior only was evaluated in healthy participants. The reported coupling ratios may differ in persons with hip or back pain. The ratios also may differ in the presence of abnormal bony morphology of the hip.

5. Conclusions

To the best of our knowledge, this study is the first to systematically explore the coupling behavior between the pelvis and femur during a dynamic task, across varying degrees of hip flexion. A consistent pattern of kinematic coupling of anterior pelvis tilt and internal femur rotation and, conversely, posterior pelvis tilt and external femur rotation, was observed at hip flexion angles ranging from 0–90°. For every 5° of anterior pelvis tilt there was 1.2–1.6° of internal femur rotation and for every 5° of posterior pelvis tilt there was a similar 1.2–1.6° of external femur rotation. Our findings suggest that altered pelvis control or positioning in the sagittal plane has the potential to influence transverse plane motion of the femur. Our findings may have clinical applications, particularly for populations that exhibit altered pelvis or femur kinematics.

Conflict of interest statement

There are no conflicts of interest to disclose.

References


