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Original research

Trunk and lower extremity segment kinematics and their relationship to pain following movement instruction during a single-leg squat in females with dynamic knee valgus and patellofemoral pain

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ABSTRACT

Objectives: To understand how instructing females with patellofemoral pain to correct dynamic knee valgus affects pelvis, femur, tibia and trunk segment kinematics. To determine if pain reduction in the corrected condition was associated with improved segment kinematics.
Design: Cross-sectional.
Methods: A 3D-motion capture system was used to collect multi-joint kinematics on 20 females with dynamic knee valgus and patellofemoral pain during a single-leg squat in two conditions: usual movement pattern, and corrected dynamic knee valgus. During each condition pain was assessed using a visual analog scale. Pelvis, femur, tibia and trunk kinematics in the frontal and transverse planes were compared between conditions using a paired *T*-test. Pearson correlation coefficients were generated between visual analog scale score and the kinematic variables in the corrected condition.
Results: In the corrected condition subjects had increased lateral flexion of the pelvis toward the weight-bearing limb ($p < 0.001$), decreased femoral adduction ($p = 0.001$) and internal rotation ($p = 0.01$). A trend toward decreased tibial internal rotation ($p = 0.057$) and increased trunk lateral flexion toward the weight-bearing limb ($p = 0.055$) was also found. Lower pain levels were associated with less femoral internal rotation ($p = 0.04$) and greater trunk lateral flexion toward the weight-bearing limb ($p = 0.055$).
Conclusions: Decreased hip adduction after instruction was comprised of motion at both the pelvis and femur. Decreased pain levels were associated with lower extremity segment kinematics moving in the direction opposite to dynamic knee valgus. These results increase our understanding of correction strategies used by females with patellofemoral pain and provide insight for rehabilitation.

1. Introduction

Dynamic knee valgus, a faulty movement pattern where the knee collapses medially during weight-bearing, has been proposed to contribute to the development of patellofemoral pain (PFP),[1] one of the most common orthopedic conditions encountered in sports medicine.[2] Characterized by increased hip adduction, hip internal rotation, knee abduction, and knee external rotation, dynamic knee valgus theoretically increases stress on the patellofemoral joint by decreasing the magnitude of contact area and shifting the location of contact to the lateral aspect of the joint.[1,3] As such, recent intervention strategies for PFP have begun to address control of the lower extremity in the frontal and transverse planes.[4,5]

In a study by Salsich and colleagues[4] it was found that when females with PFP were instructed to intentionally alter their lower limb alignment to reduce or “correct” dynamic knee valgus, hip adduction and knee external rotation decreased, however, the contribution of individual body segments, such as pelvis, femur, and tibia to the hip and knee kinematics was not examined. The investigation of lower extremity segment kinematics could shed a light on the strategies involved in correcting the dynamic knee valgus movement pattern. For example, the reduction in hip adduction[4] could have been due to a change in femur kinematics, pelvic kinematics or a combination of the two. In addition to lower extremity segments, the trunk also may play a role in the modification of dynamic knee valgus. Recent studies have documented that poor neuromuscular control of the trunk predicts knee injuries

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in females.[6,7] Other investigators have reported a negative correlation between hip abductor strength and trunk lateral flexion toward the ipsilateral side during jump landing,[8] and a trend toward decreased peak trunk lateral flexion toward the non-weight bearing limb during running.[9] Hence examining how the trunk responds to changes in lower extremity alignment could provide insight into the mechanism of PFP. To date only one study has investigated trunk and pelvis movement together with lower limb kinematics in females with PFP.[10] In this study, females with PFP presented with greater trunk lateral flexion toward the weight-bearing limb together with contralateral pelvic drop, greater hip adduction and knee abduction than controls during a single-leg squat.[10] What remains unknown is how the trunk responds when people attempt to correct a faulty lower extremity movement pattern.

The aim of this study was to determine the changes in pelvis, femur, tibia and trunk segment kinematics following instruction to correct a dynamic knee valgus pattern during a single-leg squat in females with PFP. A secondary purpose was to determine if pain reduction in the corrected condition was associated with improved segment kinematics.

In this study we examined pelvis, femur, tibia, and trunk segment kinematics in the subjects who participated in the previously mentioned published study[4] investigating only hip and knee kinematics during the correction of dynamic knee valgus. We compared segment kinematics in the frontal and transverse planes in two movement conditions: usual movement condition and corrected dynamic valgus condition. The hypotheses were the following. First, in the corrected condition the pelvis, femur and tibia would show a movement pattern consistent with decreased dynamic knee valgus (i.e. decreased contralateral pelvic drop, femur adduction, femur internal rotation, tibia abduction, and because segment motion is calculated relative to the laboratory, decreased tibia internal rotation). Second, we expected that trunk lateral flexion toward the weight-bearing limb would be decreased in the corrected condition compared to the usual condition. Third, decreased pain level was expected to correlate with improved segment kinematics in the corrected condition.

2. Methods

Twenty females with chronic PFP, who were between 18 and 40 years of age, participated in the study (mean (SD) age: 22.4 (4.3) yrs, height: 167.2 (6.5) cm; body mass: 62.5 (7.6) kg; pain duration: 4.5 (4.6) yrs; average pain in last week: 4.0 (1.3) out of 10). Fourteen subjects had bilateral PFP. The study was approved by Ethics Committee: Institutional Review Board of Saint Louis University (number 15477). All subjects read and signed an informed consent form before participating and the tenets of the Declaration of Helsinki were followed. To be included in the study, subjects needed to have: (1) pain originating from the patellofemoral articulation behind or around the patella assessed by palpation to rule out pain originating from the patellar tendon, quadriceps tendon, tibiofemoral joint, meniscii, or synovial plicae; (2) PFP of at least 2 months duration[11] with average pain level during the past week being equal or above 3 on a scale where 0 represented no pain, 10 represented severe pain[12]; (3) pain elicited with two of three provocation tests (resisted isometric quadriceps contraction at ~10° knee flexion, squatting, prolonged sitting, stair ascent or descent)[12]; (3) presence of observable dynamic knee valgus during the descent phase of a single leg squat (visual assessment of the frontal plane knee angle (abduction) greater than 10°)[13] performed with their involved or most painful limb. Exclusion criteria were: (1) BMI greater than 30 kg/m^2; (2) a history (or current report) of knee ligament, tendon or cartilage injury, traumatic patellar dislocation, patellar instability, prior knee surgery, known pregnancy, neurological involvement that would influence coordination or balance during movement testing; (3) the absence of observable dynamic knee valgus. To confirm that all inclusion and exclusion criteria were met, subjects underwent a clinical screening examination of the knee joint by the principal investigator (a physical therapist with 24 years of experience). If inclusion criteria were met, the subject returned on a different day to complete the testing procedures.

Forty-six female subjects met the age and BMI criteria and were screened in person. Twenty-four of those screened did not meet at least one of the remaining criteria and were excluded (Supplementary material). Of the 22 remaining subjects, 2 were unable to complete the tasks as instructed during the testing procedures and were excluded. Twenty subjects completed all testing procedures.

Kinematic data (120 Hz) were collected using an 8-camera 3D motion capture system (Vicon Nexus, Los Angeles, CA) and a 6-degrees-of-freedom model/marker set (Visual3D, C-motion, Inc.). For all subjects, retro-reflective markers were placed on pelvis and lower limbs as previously described.[4,14] Trunk markers were placed on the last 10 subjects as previously described.[14] Subjects wore their own running shoes, and all subjects denied wearing orthotic inserts. Before data collection a calibration trial was collected for each subject. The experimenter demonstrated the task to each subject by performing a squat with the non-weight-bearing knee flexed (lower leg behind the body). Subjects performed the squat on their involved limb (or most painful limb if bilateral PFP) while keeping their arms out to their sides.

Subjects were instructed to complete each squat (from start of knee flexion back to full knee extension) in 4 s.[15] Subjects were allowed several practice trials to become comfortable with the task. Subjects started each trial with both feet on the ground (squat trials were separated by 10–15 s). The squat was performed under 1 additional condition: avoidance (correction) of dynamic knee valgus. For the corrected condition, subjects were instructed to “keep your knee over the middle of your foot (do not let your knee fall in)” during the descent phase of the squat.[4] The corrected condition was demonstrated first, and subjects were allowed several practice trials to get accustomed to the movement. The term ‘corrected’ was not verbalized to subjects in order to prevent bias in pain assessment.[4] Three trials of each movement condition were recorded, and between conditions subjects had 5–10 min of rest. A squat cycle was defined as the period between the start of knee flexion and the return to full knee extension. Subjects completed a visual analog scale (VAS)[16] after each condition to rate their average pain during that particular condition.[4]

The 6-degrees-of-freedom model incorporated the trunk, pelvis, thigh, shank and foot as previously described.[4,14] Data were processed in Vicon for marker labeling and in Visual3D (C-Motion, Inc.) to apply the 6-degrees-of-freedom model. Marker trajectories were lowpass filtered (6 Hz, 4th order Butterworth filter) and then imported into Matlab R2010b (The MathWorks, Inc).

Peak knee flexion (PKF) was selected as time event between the start of movement (SOM) and the end of movement (EOM). The time of peak knee flexion was chosen based on pilot data which showed that the time of peak knee flexion was coincident (within 1–2 samples) with the time of peak knee extensor moment, a point of peak patellofemoral joint stress.

The SOM was defined as the first time point at the start of the descent phase at which the angular velocity of the knee joint in the sagittal plane was greater than zero, and EOM was defined as the last time point at the end of the ascent phase at which the angular velocity of the knee joint in the sagittal plane was less than zero. Visual inspection of each repetition ensured the algorithm accuracy.