MOVEMENT DYSFUNCTION DURING THE MID-STANCE PHASE OF GAIT AFTER ACUTE, ISOLATED ACL RUPTURE

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INTRODUCTION
Individuals who experience knee instability (non-copers) (1) after acute anterior cruciate ligament (ACL) rupture have been found to have altered movement patterns. Notably, knee flexion angles are reduced during the weight acceptance phase of the gait cycle in conjunction with altered muscle activation strategies (2, 3). The weight acceptance (heelstrike to peak knee flexion) phase of gait is frequently studied after ACL injury as knee stability is challenged during early stance: the quadriceps muscles contract eccentrically to control increasing knee flexion motion.

The mid-stance phase of gait (peak knee flexion to peak knee extension during stance) exposes the knee to distinct challenges. The primary goal during this phase of gait is to maintain stability as the limb moves into single limb support. However, movement patterns during the mid-stance phase of gait have not been described for a non-coper population. If ACL injury does result in altered movement and muscle strategies during mid-stance, what are the potential consequences of this movement dysfunction? The purpose of this study is to identify changes in knee kinematics and muscle activity during a discrete phase of the gait cycle among a homogenous patient population after acute, isolated, ACL rupture.

METHODS
Subjects: Twenty-one individuals with acute, isolated, unilateral ACL rupture were categorized as non-copers (NC) through a screening examination (4). All participants were highly active prior to injury and had no impairments (i.e., pain, effusion, limited knee motion) at the time of motion analysis testing. The study protocol was approved by the University of Delaware Human Subject Committee and all participants gave written informed consent.

Motion Analysis: A six camera, passive, three-dimensional motion analysis system captured kinematic data (VICON 512, Oxford Metrics, London, England) at a frequency of 120 Hz. Data were collected during trials with the subject walking along a 13m path at their intentional walking speed. Five trials each were collected and averaged for the injured (I) and uninjured (U) limbs.

Kinematic Variables: Sagittal plane knee motion was calculated using rigid body analysis. The interval of interest was mid-stance, defined as the point of peak knee flexion to peak knee extension during the stance phase of gait.  

EMG Variables: Electromyographic (EMG) data from the vastus lateralis, vastus medialis, medial and lateral hamstrings, medial and lateral gastrocnemius, soleus and tibialis anterior muscles were collected. Maximal voluntary isometric contraction (MVIC) and resting EMG signals were collected from each muscle group. The average rectified value (ARV), peak values, and muscle co-contraction indexes for quadriceps-hamstring muscles (3) were calculated for the mid-stance phase of gait.

Data Analysis: Paired t-tests were used to identify differences between the injured and uninjured limbs. The variables of interest included sagittal plane knee angles and excursions (reported in degrees), and average rectified values and peak values (reported as % MVIC). Linear regression was performed to identify relationships between muscles responsible for controlling sagittal plane knee excursion. Significance was established at p < 0.1 for EMG variables secondary to the highly variable nature of EMG activity. Significance was established at p<0.05 for kinematic variables as well as R² values.

RESULTS
Kinematics: The knee flexion angle was significantly greater on the injured versus uninjured limb (I X= 4.72 (3.51), U X=2.04 (4.55), p=0.028) as the injured limb underwent less excursion from peak knee flexion to peak knee extension (I X=19.48 (6.09), U X=25.31 (4.62), p<0.001) (FIGURE).

Muscle Activity: The ARV for the soleus was significantly lower on the injured limb compared to the uninjured limb (I X=5.32 (4.38), U X=2.88 (2.37), p=0.027) as was vastus lateralis-lateral hamstring co-contraction (I X=2.94 (2.12), U X=1.89 (0.89), p=0.04).

DISCUSSION
Non-copers demonstrated a crude stabilization strategy that impacted kinematics during the mid-stance phase of gait: there was less knee motion and the soleus was less active during this portion of stance compared to the uninjured limb. With the foot in a closed chained position, the soleus may function as an ACL agonist and oppose anterior tibial translation (5). Furthermore, during mid-stance the soleus functions to control forward tibia progression (6). Given the normal function of this muscle, these alterations in soleus muscle activity may be considered an undesirable neuromuscular adaptation following ACL rupture.

Together, the higher lateral hamstring activity and higher vastus lateralis-lateral hamstring also represent negative adaptations to keep the knee stable as the knee extends in mid-stance. The hamstring can contribute directly to knee flexion. A more flexed knee may be more stable after ACL injury by putting the hamstrings, an ACL agonist, at a mechanical advantage to restrain anterior tibia movement. The role of the lateral aspect of both muscle groups may have occurred in response to the increased anterior excursion of the lateral tibia plateau that occurs after ACL rupture (7).

The muscle strategies implemented by non-copers during mid-stance phase of gait allows this population to achieve the goal of maintaining knee stability during single limb support. Kinematics were sacrificed for the sake of knee stability in the form of decreased sagittal plane excursion. The absence of normal knee motion during mid-stance has the potential to be particularly damaging to articular surfaces since there is only one limb to support the entire body.

Results of this study indicate the mid-stance phase of gait is altered after ACL rupture. Decreased knee excursion is a characteristic shared with the weight acceptance phase of gait. However, alterations in soleus muscle activity and the influence of hamstring muscle activity on knee excursion are unique to this portion of the gait cycle. Evaluation of mid-stance may be useful in investigations of neuromuscular characteristics of this patient population.

REFERENCES

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