HAMSTRINGS WEAKNESS INCREASES ACL LOADING DURING SIDESTEP CUTTING

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INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most debilitating and costly lower extremity injuries experienced by athletes [1]. It has been shown that 70% of ACL ruptures occur in a noncontact situation, specifically during rapid decelerations of the body’s center of mass [2].

Several non-modifiable and modifiable factors have been associated with increased risk of ACL injury. One such modifiable risk factor that has received considerable attention is relative hamstrings to quadriceps muscle strength (H:Q) ratio. In vitro studies have demonstrated that a decreased H:Q ratio results in decreased knee joint stability and increased ACL loading [3]. Furthermore, a decreased H:Q ratio has been identified prospectively as a risk factor for ACL injury [4]. Therefore, the purpose of this study was to determine the relationship between H:Q ratio and ACL loading during sidestep cutting using a musculoskeletal modeling approach.

METHODS

Twenty recreationally active females (21 ± 1 years, 61.8 ± 6.4 kg, 1.66 ± 0.05 m) volunteered to perform sidestep cutting maneuvers before (UC) and after (FC) an isokinetic knee flexion fatigue protocol. Three-dimensional joint kinematics of all UC and FC trials were collected using a ten-camera Motion Analysis Eagle system (200 Hz), and force plate data were collected with an AMTI force platform (1000 Hz).

A participant-specific musculoskeletal model was then generated in OpenSim [5] consisting of 21 degrees-of-freedom (dof). The left leg was actuated by joint torque actuators, while the right leg and back were actuated by 43 Hill-type muscle actuators. Each muscle’s maximum isometric force ($F_0^m$) in the musculoskeletal model was scaled according to each participant’s peak isokinetic strength for UC trials. For FC trials, $F_0^m$ of the hamstrings were rescaled according to each participant’s peak isokinetic knee flexion strength measured after the fatigue protocol to simulate cutting maneuvers performed with reduced hamstrings strength. Pelvis position and orientation relative to the ground was defined with 6-dof. The head, arms and torso were represented as a rigid segment connected with the pelvis by 3-dof. Each hip was modeled as a 3-dof ball-and-socket joint. The left knee was modeled as a 1-dof revolute joint, while the right knee was modeled as a 3-dof joint. Both ankles were modeled as 1-dof revolute joints. Computed muscle control (CMC) was then implemented to produce forward dynamic simulations for all UC and FC trials generally consistent with the experimentally measured kinematics [6]. Optimal CMC input parameters were found using an optimization algorithm to minimize kinematic errors and residuals [7].

Musculoskeletal model outputs were used in a three-dimensional knee model to calculate ACL force. Dependent t-tests were used to assess differences in ACL force between UC and FC trials. Other variables of interest included timing of peak ACL force, as well as sagittal, frontal and transverse plane ACL loading. Significance for all tests was set at $p < 0.05$.

RESULTS AND DISCUSSION

Reduced hamstrings muscle strength resulted in a 22.8% increase in peak $F_{ACL}$ during sidestep cutting (Figure 1). This increase was primarily due to a 32.4% increase in the sagittal plane ACL loading.
Additionally, reduced hamstrings strength resulted in greater frontal plane ACL loading due to an increase in knee abduction moment, although this difference was not significant.

In the sagittal plane, decreased hamstrings force production significantly reduced tibiofemoral contact force despite an increase in vertical ground reaction force and no change in quadriceps force production. This reduction in tibiofemoral contact force would theoretically reduce sagittal plane ACL loading. However, decreased knee flexion angle at peak $\text{F}_{\text{ACL}}$ caused the hamstrings angle of pull to become more axial with the tibia. This change, coupled with an overall decrease in hamstrings force production resulted in a significantly reduced posteriorly directed hamstrings shear force thereby increasing sagittal plane ACL loading and yielding a net increase in $\text{F}_{\text{ACL}}$. The increase in $\text{F}_{\text{ACL}}$ suggests that injury risk may be subsequently increased in athletes with a decreased H:Q ratio. These results are consistent with the findings of Myer et al. [4] who prospectively identified decreased hamstrings strength as a risk factor for ACL injury.

CONCLUSIONS

Results of the current model suggest that a decreased H:Q ratio significantly increases ACL loading. While the increase in $\text{F}_{\text{ACL}}$ was not enough to rupture the ligament, it is possible that repeated performance of a high-risk maneuver, such as sidestep cutting, with imbalanced muscle strength may ultimately lead to ligament failure [1]. Furthermore, previous research has shown that the ability to decelerate upon initial ground contact and to control knee loading may be related to a balanced H:Q ratio [8]. Thus, increased balance in hamstrings relative to quadriceps muscle strength may be a mechanism that protects the ACL [4]. Preseason screening programs that monitor H:Q ratio may be warranted to identify female athletes with potential deficits. Targeted neuromuscular interventions that increase relative hamstrings muscle strength may then subsequently decrease injury risk.

Table 1. Effects of fatigue on mean ± stdv peak ACL loading ($\text{F}_{\text{ACL}}$), time of peak $\text{F}_{\text{ACL}}$, and the planar components of $\text{F}_{\text{ACL}}$.

<table>
<thead>
<tr>
<th></th>
<th>UC</th>
<th>FC</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak $\text{F}_{\text{ACL}}$ (N·kg$^{-1}$)*</td>
<td>11.02 ± 4.65</td>
<td>13.53 ± 3.53</td>
<td>0.001</td>
</tr>
<tr>
<td>Time of peak $\text{F}_{\text{ACL}}$ (ms)</td>
<td>27 ± 7</td>
<td>27 ± 7</td>
<td>0.988</td>
</tr>
<tr>
<td>Planar components at peak $\text{F}_{\text{ACL}}$ (N·kg$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sagittal*</td>
<td>6.79 ± 3.43</td>
<td>8.99 ± 2.90</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Frontal</td>
<td>2.89 ± 1.13</td>
<td>3.37 ± 0.93</td>
<td>0.059</td>
</tr>
<tr>
<td>Transverse</td>
<td>1.35 ± 1.19</td>
<td>1.18 ± 0.57</td>
<td>0.719</td>
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* indicates UC is significantly different from FC ($p<0.05$).

REFERENCES


ACKNOWLEDGEMENTS

International Society of Biomechanics Dissertation Grant
University of Wisconsin-Milwaukee Dissertation Fellowship
UWM College of Health Sciences Student Research Grant