INTRODUCTION

Knee injuries, particularly ruptures of the anterior cruciate ligament (ACL), are common among young athletes, and are widely accepted to be multi-factorial [1]. The quadriceps muscles (Q), hamstrings muscles (H), and knee ligaments are thought to stabilize the knee during high risk movements; however, the specific role of muscle forces with regard to ACL injury remains unknown.

Single-leg landing is one activity where ACL injuries routinely occur, and the timing of such injuries is hypothesized to be at the time of peak ground reaction force (GRF) [2]. Thus, an understanding of muscle co-contraction at peak GRF may lead to improved training methods for injury prevention. Hamstrings activation protects the ACL during landing [1], while quadriceps activation may endanger the ACL through an anterior force on the tibia. Despite this, the quadriceps muscles are needed to decelerate the body during landing and stabilize the knee joint. Li et al. [3] showed that quadriceps and hamstrings co-contraction effectively reduce ACL loading.

It is nearly impossible to observe ACL injuries during in vivo testing; however, the combination of motion analysis and musculoskeletal modeling techniques can provide estimates of muscle forces during a landing maneuver. The Q/H force ratio at the time of peak GRF can show the net effect of both Q and H forces at the most likely instance of ACL injury. A Q/H force ratio that is substantially greater than one may indicate reduced ACL protection. We hypothesized that for increased landing heights, the knee muscles would be coordinated to increase protection of the ACL; that is, the Q/H ratio would be closer to one.

METHODS

Eight healthy male subjects were recruited from the National University of Singapore with a mean [standard deviation] age of 22.9 [0.6] years, height of 1.70 [0.03] m and weight of 67.2 [6.9] kg. The subjects performed single-leg drop landing tasks from heights of 30cm and 60cm in a motion analysis laboratory. 6 motion capture cameras (Vicon) measured skin-mounted marker trajectories and two force plates (Kistler Inc.) measured ground reaction forces.

OpenSim musculoskeletal modeling software [4] was used to develop muscle-actuated simulations of each subject’s landing maneuvers. A generic model was scaled to each subject’s dimensions, and an inverse kinematics (IK) procedure was used to obtain joint kinematics. A Residual Reduction Algorithm (RRA) was employed to produce a set of dynamically consistent joint angles. Muscle forces were computed using static optimization, with an objective function of minimizing activation.

The landing phase was defined from foot-strike to maximum knee flexion angle (Fig. 1), and the time of peak GRF was selected for statistical analysis. A paired t-test was used to identify differences in Q/H force ratio between the landing maneuvers.

RESULTS

Peak GRF occurred between 15-45% of the landing phase. Q/H ratios were greater at the time of peak GRF than at foot-strike at 30 and 60cm (p<0.005 and p<0.002 respectively). The Q/H force ratio did not display a significant difference between landing heights at the time of peak GRF, despite the 30cm landing mean being 174% of the 60cm landing mean (Table 1). At foot-strike, the Q/H force ratios were almost identical for both landing heights.

DISCUSSION

The Q/H ratio was greater at peak GRF compared to foot-strike for both landing maneuvers. At peak GRF, the quadriceps force was substantially greater (2.1 BW) than at foot-strike, in order to decelerate the body and maintain postural stability. The associated increase in Q/H ratio supported the hypothesis that ACL injuries are more likely to occur at this point in time. At foot-strike, both landing maneuvers displayed similar mean Q/H ratios, which were close to one. The quadriceps and hamstrings muscle forces were also fairly similar between both maneuvers. These findings suggested a minimal difference in the subjects’ knee muscle coordination patterns prior to the landing phase for both maneuvers.

There was no significant difference in the mean Q/H force ratio at peak GRF between the two landing maneuvers, which disproved our hypothesis. However, the mean Q/H value for the 60cm landing was appreciably closer to one than the corresponding value for the 30cm landing, and displayed a small standard deviation. One possible explanation could be that landing from an increased height requires an increase in hamstrings force to protect the ACL, which consequently lowers Q/H. Future studies, with larger cohorts for statistical power, are needed to determine the relationship of the ACL tension and Q/H muscle force ratio to better understand the causes of rupture.

SIGNIFICANCE

The role of knee muscle co-contraction in protection of the ACL during landing maneuvers may provide clues to rupture mechanisms of this ligament. This knowledge may lead to the development of targeted training regimes that aim to prevent these costly and debilitating injuries.

REFERENCES