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Research article

Muscle activity response to external moment during single-leg drop landing in young basketball players: The importance of biceps femoris in reducing internal rotation of knee during landing

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Abstract

Internal tibial rotation with the knee close to full extension combined with valgus collapse during drop landing generally results in non-contact anterior cruciate ligament (ACL) injury. The purpose of this study was to investigate the relationship between internal rotation of the knee and muscle activity from internal and external rotator muscles, and between the internal rotation of knee and externally applied loads on the knee during landing in collegiate basketball players. Our hypothesis was that the activity of biceps femoris muscle would be an important factor reducing internal knee rotation during landing. The subjects were 10 collegiate basketball students: 5 females and 5 males. The subjects performed a single-leg drop landing from a 25-cm height. Femoral and tibial kinematics were measured using a 3D optoelectronic tracking system during the drop landings, and then the knee angular motions were determined. Ground reaction forces and muscle activation patterns (lateral hamstring and medial hamstring) were simultaneously measured and computed. Results indicated that lower peak internal tibial rotation angle at the time of landing was associated with greater lateral hamstring activity ($r = -0.623$, $p < 0.001$). When gender was considered, the statistically significant correlation remained only in females. There was no association between the peak internal tibial rotation angle and the knee internal rotation moment. Control of muscle activity in the lateral to medial hamstring would be an important factor in generating sufficient force to inhibit excessive internal rotation during landing. Strengthening the biceps femoris might mitigate the higher incidence of non-contact ACL injury in female athletes.

Key words: ACL injury, risk factors, knee moment, muscle activation.

Introduction

In many sports injuries, anterior cruciate ligament (ACL) injury is known to be serious enough to require a relatively long time for athletes to return to sports activities. Despite improvements in anterior cruciate ligament reconstruction techniques, two-thirds of ACL patients do not return to the pre-injury level of competitive sports by 12 months (Ardern et al., 2011). Therefore, ACL injury prevention is an important issue for athletes.

The main focus of preventing ACL injury has been avoiding non-contact injury. The rate of non-contact injury among ACL injuries is approximately 70% (Hewett et al., 2006). Moreover, contact injury of the ACL, which occurs as a result of player-to-player contact, usually results from unanticipated situations and is unavoidable in contact sports. Thus, it is important for prevention to find out the reason why ACL injury occurs in non-contact situations. Gender differences in the incident rate have been a focus in exploring the mechanism of non-contact ACL injury. The injury rate is 3.3–4.9 times higher in female athletes than in male athletes in basketball and soccer (Agel et al., 2005). There have been numerous studies concerning the kinematic differences in the knee joint between males and females in non-contact situations (Chappell et al., 2007; Ford et al., 2003; Kernozek et al., 2005; Kiriyama et al., 2009; Nagano et al., 2007; Russell et al., 2006). Female athletes exhibit increased knee valgus and decreased knee flexion in cutting tasks (James et al., 2004; Malinzak et al., 2001), and increased knee valgus and increased knee internal rotation in landing tasks (Chappell et al., 2007; Ford et al., 2003; Kernozek et al., 2005; Nagano et al., 2007; Russell et al., 2006). Quatman et al. (Quatman and Hewett, 2009) suggested that frontal as well as sagittal and transverse plane loading mechanisms likely contribute to the resultant ACL loading. One possible mechanism may be that excessive knee internal rotation in conjunction with knee valgus at the time of landing leads to ACL injuries.

Though anterior translation of the tibia has been thought to be caused during landing, the anterior translation of the tibia may not actually occur during landing. This is because posterior forces on the tibia, which cause posterior translation of the tibia, are generated at the time of landing against anterior translation of the tibia produced by quadriceps contraction (Shin et al., 2007). Thus, anterior tibial translation is not the likely mechanism of ACL injuries during landing. If this is the case, then inhibiting internal rotation during landing would be more important for preventing non-contact ACL injuries.

Lower external tibial rotation strength leads to excessive internal tibial rotation because the muscle force is insufficient to inhibit the internal rotation. Kiriyama et al. (2009) found that females had less external tibial rotation strength than males and that external tibial rotation strength was negatively correlated with the peak internal knee rotation angle during landing. However, it still remains to be shown whether females sustain greater externally applied internal rotation moment of the knee during landing, or whether females cannot generate sufficient external rotational moment against the externally applied internal moment of the tibia relative to the femur, even if

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it is equivalent to what is applied to males.

To assess which is responsible for the greater internal knee rotation during landing in females—namely, increased knee internal moment or decreased external rotation muscle activity—we compared kinematic, kinetic, and electromyographic characteristics between males and females. The purpose of this study was to investigate the relationship between internal rotation of the knee and muscle activity from internal and external rotator muscles, and between internal rotation of the knee and externally applied loads on the knee during landing in collegiate basketball players. We hypothesized that females who showed less external rotator muscle activity would demonstrate significantly reduced internal knee rotation during landing.

Methods

Participants

Subjects were recruited from members of a male and female college basketball team. Ten healthy college students, including 5 males (mean age = 22.4 ± 2.8 yr; mass = 66.0 ± 9.3 kg, height = 1.74 ± 0.05 m) and 5 females (mean age = 21.0 ± 1.4 yr, mass = 53.4 ± 6.7 kg, height = 1.56 ± 0.05 m) volunteered. Inclusion criteria were that the subjects had no history or compliant of chronic pain, major injury, surgery to the lower limbs or low back. All subjects were informed about the procedure and purpose of the study. The protocol of this study was approved by the ethics committee of the project leader's institute.

Instrumentation

Kinematic data were collected using two Optotrak cameras (OPTOTRAK 3020, Northern Digital Inc, Ontario, Canada). The sampling rate of the motion analysis system was set at 240 Hz. Marker arrays, containing 5 infrared light-emitting diodes (LEDs) mounted on a metal plate, were tightly secured onto the middle thigh and proximal shank, which was a non-dominant limb identified as the preferred stance limb used to kick a ball, using an elasticized band. Two additional markers were placed over the knee joint line in order to determine the relative joint center of rotation for the knee. A force plate (OR6-6-2000, AMTI, Watertown, MA, USA) embedded in the middle of the capture volume was used to measure the ground reaction force and the location of the center of pressure at the time of landing. The sampling rate of the force plate was set at 960 Hz. Surface electromyography (EMG) electrodes (SX230, Biometrics, Gwent, UK) were placed on the non-dominant-side biceps femoris (lateral hamstring) and semimembranosus/semitendinosus (medial hamstring) after the skin surface was shaved, abraded, and cleaned with alcohol. A single ground electrode was placed on the wrist. The EMG signals were amplified (gain, 1000), band-pass filtered (20–460 Hz) and recorded. The data were digitized and entered into a PC with a sampling rate of 960 Hz. The three-dimensional coordinates of the LEDs markers, the force plate and EMG signals, were synchronized by ODAU II (Optotrak Data Acquisition Unit II, Northern Digital Inc, Ontario, Canada).

Testing procedure

Before landing testing, subjects were required to perform a static standing trial in order to define the segment coordinate system for each limb in a global (force plate) coordinate system (Nigg et al., 1998). The subjects were instructed to stand in a neutral position aligned with the global coordinate system as closely as possible. The translation vector and rotation matrix from the segment coordinate system to the global coordinate system were then calculated using singular decomposition methods while the subjects performed test movements (Challis 1995, Challis, 1995; Söderkvist and Wedin, 1993).

The subjects were asked to perform a drop landing onto the force plate from a 25 cm-h-high box located 35 cm behind the force plate. They were barefoot, and folded their arms over their chest during the landing. The subjects were asked to stand on their dominant leg on top of the box, and drop land onto their non-dominant leg to the force plate without jumping. We discarded trials in which the dominant foot touched down during the landing. Three successful trials were obtained for each subject.

Data processing

Raw kinematic data were linearly interpolated to force-plate data. The knee joint center was calculated as the centroid of the medial and lateral femoral epicondyles. Three-dimensional knee angles were calculated using Euler angle rotations of the tibia relative to the femur. The translation and rotation matrix were computed from marker coordinates using MATLAB software (version 7.0, MathWorks, Inc., Natick, MA) according to Kiriyama (2009).

To calculate the net external rotational moment (the moment around the vertical axis) on the target side of the knee, which has been termed the floor reaction force vector approach by Winter (2010), the leg and the foot were combined as one rigid body. The rotational knee moment was determined by finding the component of the ground reaction force moment along the knee joint axis under the assumption that the segment mass and inertia were negligible. This was justified because the segment mass, the radii of gyration, and the angular accelerations are small in the horizontal plane relative to the external rotational moment. The external rotational moment was normalized to the subject’s weight (Nm/kg). The foot contact was defined as the vertical ground reaction force exceeding 10 N.

The EMG signals of the lateral and medial hamstring muscles collected during landings were quantified as root mean square (RMS) values. These values were averaged over 50 milliseconds before and after the peak internal rotation angles at the time of landing (Figure 2). The averaged signals were normalized to EMG signals recorded for the tested muscles during maximum voluntary isometric contraction (MVIC). The EMG signals of the MVIC were also quantified as RMS values. The average EMG of the MVIC was calculated over a 10-millisecond period encompassing the maximum activity. For the MVIC test, the subject was lying prone on a bed. The subject’s foot was held by the examiner’s hand at external and internal rotation for selectively activating the

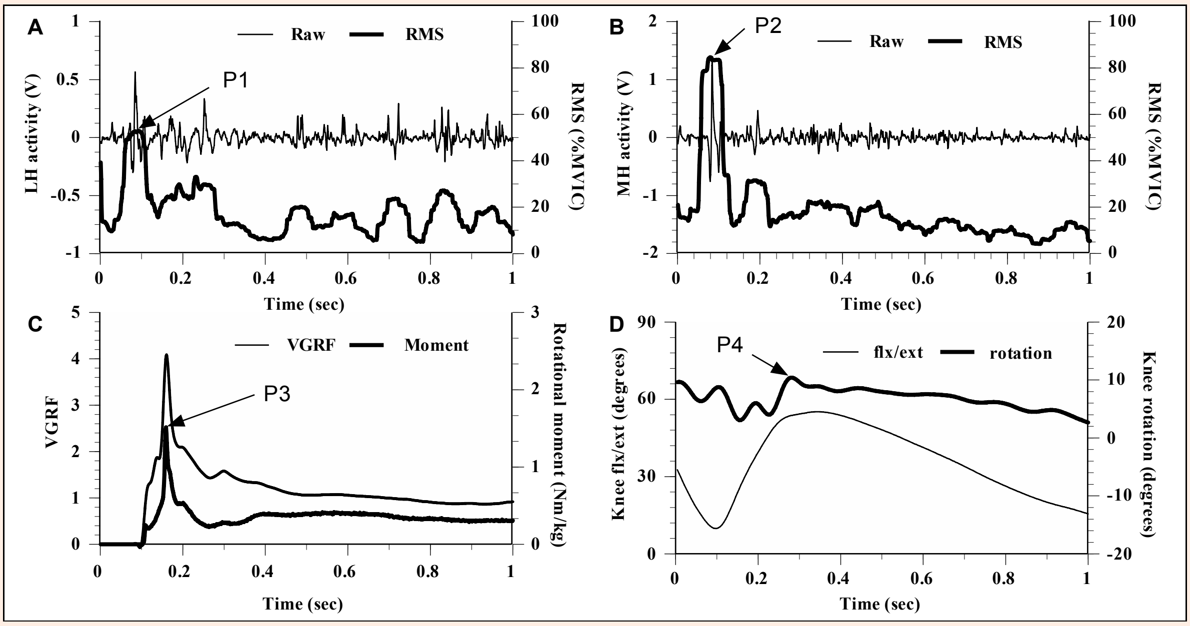

Figure 1. Kinetic, kinematic, and EMG data from a representative subject during drop landing. Each graph demonstrates the parameters used for the analysis. (A) Lateral hamstring (LH) activity. The thick line indicates RMS values normalized to MVIC. The thin line indicates the raw EMG signals. P1 demonstrates the peak LH activity. (B) Medial hamstring (MH) activity. Again the thick line indicates normalized RMS values and the thin line indicates the raw signals. P2 demonstrates the peak MH activity. (C) Vertical ground reaction force (VGRF) and rotational moment around knee. P3 demonstrates peak rotational moment. (D) Knee joint angles. Positive values represent flexion (the thin line) and internal rotation (the thick line) angle of the knee. P4 demonstrates the peak internal rotation angle.

lateral and medial hamstring, respectively. The MVIC of the lateral and medial hamstring was performed with the knee of the subject fixed manually at 45 degrees. During the MVIC trials, none of the subjects was able to overcome the manual resistance. The normalized RMS values at the time of peak internal rotation were used to calculate the lateral to medial hamstring activation ratio.

Statistical analysis

Pearson's correlation coefficient was used to determine the association between the peak tibial rotation at the time of landing and the muscle activities, or between the peak tibial rotation and the externally applied rotational moment. The significance level was set at $p < 0.05$ for all analyses.

Results

Representative data of vertical force, rotational moment, tibial rotation angle, and lateral and medial hamstring activities during landing are shown in Figure 1. Internal knee rotation was found for all subjects after foot contact during single-leg drop landing. The peak internal rotation was significantly and inversely correlated with the peak lateral hamstring activity ($r = -0.623$, $p < 0.001$) (Figure 2). When each gender was analyzed separately, the statistically significant correlation remained in females ($r = -0.742$, $p < 0.001$) but not in males ($r = -0.389$, $p = 0.152$). Also, the peak internal rotation was significantly and inversely correlated with the lateral hamstring / medial hamstring ratio ($r = -0.698$, $p < 0.001$). On the other hand, no association was found between the peak internal rotation and the peak externally applied internal moment in either males or females (males, $r = -0.469$, $p = 0.078$; females, $r = -0.096$, $p = 0.734$; both, $r = -0.218$, $p = 0.248$). Also, there was no association between the peak internal rotation angle and the peak medial hamstring activity (males, $r = -0.369$, $p = 0.176$; females, $r = -0.430$, $p = 0.110$; both, $r = -0.129$, $p = 0.497$).

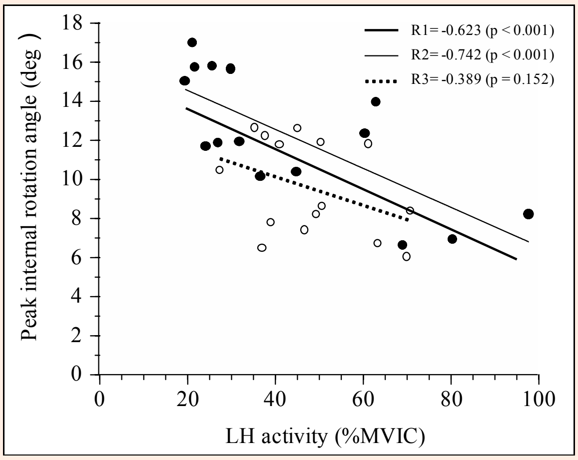

Figure 2. Relationship between peak lateral hamstring (LH) activity and peak internal rotation angle of the tibia. R1, Pearson correlation coefficient in all trials; R2, Pearson correlation coefficient in trials from females (n=15); R3, Pearson correlation coefficient in trials from males (n=15). Open circles indicate male data; filled circle indicate female data.

Discussion

As noted in the Introduction, females tend to show greater internal rotation of the tibia during landing (Chappell et al., 2007; Kiriyama et al., 2009; Nagano et al., 2007). However, it is unclear whether females sustain greater externally applied internal rotation moment of the knee during landing, or whether females cannot generate sufficient external moment against the externally applied internal moment of the knee, even if it is equivalent to what is applied to males. In this study, a moderate negative association was found between the peak internal rotation of the tibia and the peak lateral hamstring activity during landing in females but not in males. Moreover, there was no association between the internal rotation of the tibia and the externally applied internal rotation moment of the knee. These observations suggest that lower activity of the external rotator muscle of the knee, which inhibits internal rotation of the knee, may be the reason why females tend to show a large internal rotation of the knee during drop landing.

Activation of hamstring muscles has been regarded as a key factor preventing ACL injuries because it inhibits anterior translation of the tibia (Li et al., 1999; Markolf et al., 2004; Withrow et al., 2008). However, the anterior translation of the tibia may not actually occur during landing: Shin et al. (2007) suggested that anterior tibial translation is not likely the mechanism of ACL injuries during landing, but that another mechanism, such as valgus rotation, internal rotation, or a combination of the two, may be more relevant. If this is the case, the lateral hamstring muscle, which inhibits internal rotation, would be more important than the medial hamstring muscles for preventing noncontact ACL injuries.

This study demonstrates that in females, lower lateral hamstring activation, is associated with large knee internal rotation movement during single-leg drop landing. On the other hand, the maximum isometric external rotator muscle strength of the knee tended to be smaller in females than in males (Kiriyama et al., 2009, Wojtys et al., 2003). Considering these findings, females may tend not to generate sufficient external moment to inhibit internal rotation movement. Thus, the biceps femoris muscle likely plays an important role in reducing excessive internal rotation of the knee during drop landing in female athletes.

Why was a negative correlation between peak internal rotation of the tibia and peak lateral hamstring activity during landing present only in female subjects? One possible reason is the gender difference in torsional joint stiffness of the knee. Hsu et al. (2006) found that female knees had lower joint stiffness and higher rotational joint laxity than did male knees in response to combined rotator loads. Since their study used cadaveric knees, the stiffness reflected only contributions from the passive structures of the knee. This implies that muscle contraction is more important for females than males to resist forceful rotational movement of the knee.

However, it is difficult to control muscle activity voluntarily during landing for reducing internal rotation of the knee. Wojtys et al. (2003) found that female athletes could not resist forceful internal rotation of the knee as well as their male counterparts could, even when maximally activating their knee muscles. To prevent ACL injuries in females, increasing the strength of the biceps femoris muscle might help decrease the rate of noncontact ACL injuries.

A potential limitation of this study was the small sample size, which may have resulted in insufficient power to detect statistically significant associations. Despite the small sample size, we found statistical significance in the moderate association between the peak internal rotation and the peak lateral hamstring activity.

Another potential limitation was the measurement error caused by skin movement. The arrays of surface-mounted markers on the thigh and shank can move independently of the underlying bone movements. Thus, the knee joint kinematics derived from skin markers may not represent the true bone motion between the thigh and tibia (Benoit et al., 2006; 2007, Manal et al., 2002; 2003, Reinschmidt et al., 1997). Even when an examiner carefully placed and tightly secured rigid plate-embedded markers on the thigh and shank using an elastic band, the problem remained that the position of the device could slip around the thigh or shank due to skin movement (Manal et al., 2002; 2003).

Conclusion

In conclusion, females, who tended to exhibit a greater peak internal rotation angle of the knee, tended also to show a lower lateral hamstring activity at the time of landing. The lower activity of the external rotator muscle of the knee could be reason why females showed more internal rotation of the knee during single-leg drop landing.

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Key points

- Lower activity of the external rotator muscle of the knee, which inhibits internal rotation of the knee, may be the reason why females tend to show a large internal rotation of the knee during drop landing.
- Externally applied internal rotation moment of the knee during landing would not be expected to explain why female athletes tend to show excessive internal knee rotation.
- Biceps femoris strength training might help decrease the incidence of non-contact ACL injury in female athletes.

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