Anterior cruciate ligament (ACL) injury is a serious injury in sports activities. The rate of ACL injury is much higher in female athletes than in males. Female athletes demonstrate greater knee valgus than that of male athletes during landing or several other athletic tasks. Greater knee valgus during a drop vertical jump in female athletes was considered a primary neuromuscular risk factor of ACL injury. However, many uninjured athletes demonstrate knee valgus at initial contact (IC) during landing similar to that of injured athletes, which suggests that the knee alignment at one time point during landing may not provide sufficient information and an investigation of dynamic knee movement throughout the landing phase is required. Therefore, the purpose of this prospective cohort study was to reveal a difference in knee movements during single leg landing between the ACL injured and uninjured knees in junior high and high school female basketball players.

Methods: We included 44 junior high or high school female basketball players in this IRB-approved, prospective cohort study. Subjects were excluded from the study if they had a neurological, orthopedic or communication problem at measurement. All subjects provided written informed consent prior to the enrollment. The subjects underwent measurement session and were followed for two years. The subjects were instrumented with 3 reflective markers for each leg at the greater trochanter, patella and lateral malleolus. Outcome measurements included knee valgus and flexion angles computed from the projected coordinates of the three markers onto the frontal and sagittal planes, respectively. The subjects performed single leg jumping and landing (SLJL). Two digital video cameras were used to obtain two-dimensional (2D) images in the frontal and sagittal planes. Knee valgus and flexion angles during landing were obtained from 2D images using Image J software. Moreover, we calculated an index of relative frontal motion (RFM) which was defined as a frontal knee movement divided by the sagittal knee movement. Positive RFM represents the valgus movement of the knee. Statistical analysis was performed with PASW Statistics 18. Independent t tests were used to compare knee valgus angle at IC and and at maximum between ACL injured knee group (Injured) and uninjured knee group (Uninjured). The level of significance was set at p < 0.05.

Results: Of 44 subjects in this cohort, six ACL injuries in six individuals occurred during the follow up period. Therefore, six knees in six individuals were classified as the Injured group, while 66 knees in 38 athletes were as the Uninjured group. Both knee valgus and knee flexion angles did not differ between the Injured and Uninjured at either IC or maxima knee flexion (MKF) (Table 1). The knee valgus angle at IC for the Injured and Uninjured was 12.3° and 14.8° (p = 0.15), respectively. The knee valgus angle at MKF for the Injured and Uninjured was 29.3° and 27.8° (p =.73), respectively. Knee flexion angle at IC for the Injured and Uninjured was 34.0° and 37.0° (p = 0.19), respectively. Knee flexion angle at MKF for the Injured and Uninjured was 86.0° and 82.7° (p = 0.38), respectively. We found that there are repeated knee valgus/varus motion (or knee swings) during SLJL and the number of positive and negative RFM was counted in each knee (Figure 1 and 2). Five of six ACL injured knees presented with more than two positive/negative RFMs. A scatter gram (Figure 3) of the number of knee swinging versus knee valgus angle at initial contact shows that the Injured knees are at relatively smaller valgus angles with variety of the number of knee swinging.

Discussion: The purpose of this study was to reveal a difference in the knee valgus angle during single leg landing between the ACL injured and uninjured knees in junior high and high school female basketball players. Knee valgus angle at IC and MKF did not differ between the Injured and Uninjured, while knee flexion angle at IC exceeded 34.0° both groups. Five of six ACL injured knees demonstrated repeated positive/negative RFMs. Increased knee valgus was considered a risk factor for ACL injury. However, knee valgus angle in this study did not differ between the Injured and Uninjured, which suggests that an evaluation of the knee valgus angles at IC and MKF may not provide sufficient information to rule in high risk athletes for ACL injury. Moreover, knee flexion angle at IC exceeded 34.0°. Because the reported knee flexion angle at the moment of ACL injury is between 5 and 25° flexion5, the drop jump landing may not be appropriate to capture a high risk movement pattern of ACL injury. Distinguishing high risk athletes of ACL injury may require an assessment of knee motion at smaller knee flexion angles during athletic tasks.

RFM was utilized to determine the frontal knee movement divided by the sagittal knee movement. Greater RFM indicate sudden increase of valgus or varus knee movement with deceleration of knee flexion. Positive and negative RFMs were defined as valgus and varus knee movements, respectively. We observed repeated positive/negative RFM during landing. We are unaware of the reason of this abnormal knee motion and future research should be intended to determine the mechanism of knee swinging and the association between ACL injury and knee swinging.

Several limitations should be recognized. First, this study used 2D approach. Therefore, knee valgus and flexion angle may be not.
represent real measurements. Second, we had a small sample size.

In conclusion, knee valgus angle at IC and MKF did not differ between the ACL injured and uninjured knees. Five of six ACL injured knees presented with knee swinging action during jump landing. Knee swinging at low flexion angle may be related with ACL injury risk and should be investigated in the future studies.

**Significance:** Knee valgus angle at IC or MKF did not distinguish the ACL injured athletes from the uninjured athletes. Knee swinging during landing may be taken into consideration as potential risk factor of ACL injury.

**Acknowledgments:**

**References:**

**TABLE 1. Knee valgus and flexion angle at initial contact (IC) and maximal knee flexion (MKF)**

<table>
<thead>
<tr>
<th></th>
<th>Injured(\text{\textsuperscript{a}})</th>
<th>Uninjured(\text{\textsuperscript{a}})</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Valgus angle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td>12.3 ± 2.4</td>
<td>14.8 ± 4.1</td>
<td>0.15</td>
</tr>
<tr>
<td>MKF</td>
<td>29.3 ± 9.8</td>
<td>27.8 ± 10.0</td>
<td>0.73</td>
</tr>
<tr>
<td><strong>Flexion angle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td>34.0 ± 5.3</td>
<td>37.0 ± 5.3</td>
<td>0.19</td>
</tr>
<tr>
<td>MKF</td>
<td>86.0 ± 10.5</td>
<td>82.7 ± 8.5</td>
<td>0.38</td>
</tr>
</tbody>
</table>

\(\text{\textsuperscript{a}}\) Values are mean ± standard deviation.
IC: initial contact
MKF: maximal knee flexion

12.
FIGURE 1. Case 1 presented with repeated positive/negative relative frontal motion (RFM).

Time (x axis): the number of images from initial contact (IC) to maximum knee flexion (MKF).

FIGURE 2. Case 2 presented with repeated positive relative frontal motion (RFM).

Time (x axis): the number of images from initial contact (IC) to maximum knee flexion (MKF).
FIGURE 3. A scatter gram of the number of knee swingings versus knee valgus angle at initial contact.