Anterior cruciate ligament (ACL) injury is a significant cause of morbidity. According to the American Academy of Orthopaedic Surgeons, 70% of ACL injuries are the result of a noncontact injury. The ACL is the primary restraint to anterior translation of the tibia, and injury to this structure places compensatory strain across the knee joint. The anatomy, biomechanics, and physiologic responses of the knee joint are well studied. Changes in biomechanics and the relation to anatomy and pathology have led to advances in the understanding of shear forces across the knee joint. Knees with ACL deficiency have altered biomechanics and an increased rate of arthritic change associated with repetitive loading. Because of this functional impairment and disability, there is an increasing emphasis on preventive measures for ACL injury, including physical training and activity modifications.

The effect of increased posterior-inferior tibial slope angle was recognized in the relationship between increased posterior-inferior tibial slope angle and noncontact anterior cruciate ligament (ACL) injury. Does increasing the posterior-inferior tibial slope angle increase the risk of bilateral ACL injury? A computerized relational database (Access 2007; Microsoft Inc, Redmond, Washington) was used to conduct a retrospective review of patients undergoing bilateral or unilateral ACL reconstruction surgery or treatment by a single surgeon between 1995 and 2013. Included in the study were patients with bilateral and unilateral ACL injuries and patellofemoral pain syndrome with no associated ACL deficiency. Exclusion criteria included concomitant ligament injury, previous ACL reconstruction, and previous knee surgery. Also excluded were patients who did not have plain lateral radiographs. Fifty patients were randomly selected from each group. After controlling for age and Tegner activity level, the authors found that the posterior-inferior tibial slope angle was a significant predictor ($P=0.002$) of noncontact ACL injury. Mean posterior-inferior tibial slope angle for the bilateral, unilateral, and control groups was $11.8^\circ\pm2.3^\circ$, $9.3^\circ\pm2.4^\circ$, and $7.5^\circ\pm2.3^\circ$, respectively. In the group with unilateral ACL injury vs the group without ACL deficiency, a $1^\circ$ increase in posterior-inferior tibial slope angle ($P=0.03$) was associated with a $20\%$ increase in unilateral ACL injury. In those with bilateral ACL injury vs those without ACL deficiency, a $1^\circ$ increase in posterior-inferior tibial slope angle ($P=0.001$) increased bilateral knee injury by $34\%$. The difference between the mean angles of the control group without ACL deficiency and both the bilateral injury and unilateral injury cohorts was statistically significant ($P=0.003$). Increased posterior-inferior tibial slope angle is associated with an increased risk of noncontact bilateral and unilateral ACL injury. [Orthopedics. 2017; 40(1):e136-e140.]

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in patients after medial opening wedge high tibial osteotomy. As the coronal alignment was altered, unintended iatrogenic changes occurred in sagittal alignment, increasing the posterior-inferior tibial slope. Giffin et al\(^3\) showed that small, incremental changes in sagittal alignment changed the resting position of the tibia, thereby altering the anterior translation of the tibia. Tibial osteotomy was considered a possible treatment for cruciate-deficient knees as well as knees with focal osteochondral lesions. Postoperatively, these patients had increased posterior-inferior tibial slope and an associated alteration in knee biomechanics. In a cadaveric biomechanical study by McLean et al,\(^4\) knee models were cycled through a simulated axial load. Tibial translation and ACL strain were measured and correlated with the posterior-inferior tibial slope angle measured on lateral radiographs. Increases in posterior-inferior tibial slope values were associated with increases in both ACL anteromedial bundle strain and anterior tibial acceleration. In a 2006 study, Brandon et al\(^5\) reviewed 100 patients with ACL injury compared with a sex-matched control cohort of 100 patients without ACL injury and noted a clinically significant increase in posterior-inferior tibial slope angle (12\(^\circ\) in women and 10.8\(^\circ\) in men) in the group with ACL injury. They also found a difference in pivot shift grade in patients with ACL injury compared with the control cohort without ACL injury that directly correlated with the degree of posterior-inferior tibial slope. Therefore, although posterior-inferior tibial slope angle has been identified as an associated risk factor in ACL injury and a variable in biomechanical strain across the knee joint, no study has looked at a group of patients with bilateral ACL injury and attempted to quantify the risk associated with increased posterior-inferior tibial slope angle.

The current study attempted to identify an association between posterior-inferior tibial slope angle in a group of patients with bilateral noncontact ACL injury compared with a group of patients with unilateral noncontact ACL injury and a normal cohort without ACL deficiency. The study also attempted to determine whether posterior-inferior tibial slope angle significantly increased in patients with bilateral noncontact ACL injury compared with the group with unilateral ACL injury and the control cohort without ACL deficiency.

**MATERIALS AND METHODS**

After institutional review board approval was obtained, a retrospective chart review was performed to identify bilateral and unilateral noncontact ACL injuries treated by a single surgeon (G.R.B.) from 1995 to 2013. A control cohort of patients without ACL deficiency was obtained with International Classification of Diseases, Ninth Revision, code 717.7, based on a chart review for patellofemoral pain. Computer randomization was used to select 50 patients from the 3 separate groups for inclusion in the matched control study. Patients with concomitant ligament injury, previous ACL reconstruction, or previous trauma as well as those with unavailable or unacceptable lateral radiographs were excluded. Posterior slope angle, patient age, sex, body mass index, and Tegner activity level (Table 1) were recorded for population comparisons (Table 2).

Lateral radiographs for each patient were examined on an electronic picture archiving and communication system by 2 blinded observers (S.T.H., A.M.B.). Posterior-inferior tibial slope angle was measured by drawing a line perpendicular to the anatomic axis and subtracting the angle of the lateral tibial plateau from the anatomic axis. Radiographic measurements were made based on this technique, as validated by Lipps et al,\(^6\) in a study of specific measurement techniques and intraobserver reliability for posterior-inferior tibial slope angle. The use of this circle technique in the proximal tibia allowed an accurate anatomic tibial axis to be determined with a lateral knee radiograph (Figure). In addition, the circle

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**Table 1**

<table>
<thead>
<tr>
<th>Tegner Activity Level Groups</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1-3</td>
</tr>
<tr>
<td>Mid</td>
<td>4-6</td>
</tr>
<tr>
<td>High</td>
<td>7-10</td>
</tr>
</tbody>
</table>

**Table 2**

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Non-ACL Deficient</th>
<th>Unilateral ACL</th>
<th>Bilateral ACL</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, male</td>
<td>36%</td>
<td>50%</td>
<td>46%</td>
<td>.13</td>
</tr>
<tr>
<td>Age, mean (SD), y</td>
<td>28.5 (14.5)</td>
<td>23.3 (11.1)</td>
<td>20.4 (8.4)</td>
<td>.16</td>
</tr>
<tr>
<td>Body mass index, mean (SD), kg/m(^2)</td>
<td>28.1 (7.8)</td>
<td>26.7 (6.2)</td>
<td>25.5 (3.5)</td>
<td>.037</td>
</tr>
</tbody>
</table>

Abbreviation: ACL, anterior cruciate ligament.
measurements were performed in the same manner for all 150 patients.

**Statistical Methods**

To investigate the differences in mean posterior-inferior tibial slope angle among the 3 study groups (no ACL deficiency, unilateral ACL injury, and bilateral ACL injury), 1-way analysis of variance was used, followed by least significant difference pairwise comparisons.

They attempted to determine whether the posterior-inferior tibial slope angle increased significantly in patients with bilateral noncontact ACL injury compared with the group with unilateral noncontact ACL injury and the control group without ACL deficiency. A significant difference was found among the 3 study groups in mean posterior-inferior tibial slope angle ($P=.003$). Pairwise comparison showed that the mean posterior-inferior tibial slope angle in the group without ACL deficiency was significantly lower than the mean posterior-inferior tibial slope angle in both the group with unilateral ACL injury ($P=.035$) and the group with bilateral ACL injury ($P=.001$). No significant difference was found between mean posterior-inferior tibial slope angle in the unilateral and bilateral groups ($P=.20$). Group means and standard deviations are shown in Table 3. Table 4 details pairwise comparisons among group mean posterior-inferior tibial slope angle.

Results of multinomial regression showed that posterior-inferior tibial slope angle was a significant predictor ($P=.002$) of group outcomes when controlling for the effects of age and Tegner activity level. Age ($P=.055$) and Tegner activity level ($P=.066$) were not significant predictors of ACL injury in the 3 study groups when controlling for each other and posterior-inferior tibial slope angle.

In the unilateral group vs control group model, a 1° increase in posterior-inferior tibial slope angle ($P=.03$) was associated with a 20% increase in the odds of unilateral knee injury ($OR, 1.20; 95\% CI, 1.02-1.41$). Age was not a significant ($P=.16$) predictor of ACL injury in this model ($OR, 1.02; 95\% CI, 0.99-1.06$). The group with high Tegner activity showed a significant ($P=.047$) increase in the odds of unilateral knee injury ($OR, 3.6; 95\% CI, 10.1-12.8$) compared with the group with low Tegner activity. The group with midlevel Tegner activity was not significantly different ($P=.22$) from the group with low Tegner activity ($OR, 2.05; 95\% CI, 0.64-6.53$).

**Figure:** Lateral radiograph showing the circle technique that was used to measure posterior-inferior tibial slope.

**Table 3**

<table>
<thead>
<tr>
<th>Knee Group Comparison</th>
<th>Bilateral vs Unilateral Mean</th>
<th>Unilateral vs Non-ACL Deficient Mean</th>
<th>Bilateral vs Non-ACL Deficient Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>SD</td>
<td>No.</td>
<td>SD</td>
</tr>
<tr>
<td>Bilateral</td>
<td>11.8°</td>
<td>2.3°</td>
<td>50</td>
</tr>
<tr>
<td>Unilateral</td>
<td>9.3°</td>
<td>2.4°</td>
<td>50</td>
</tr>
<tr>
<td>Non-ACL deficient</td>
<td>7.5°</td>
<td>2.3°</td>
<td>50</td>
</tr>
</tbody>
</table>

*Abbreviation: ACL, anterior cruciate ligament.*

**Table 4**

<table>
<thead>
<tr>
<th>Knee Group Comparison</th>
<th>Bilateral vs Unilateral</th>
<th>Unilateral vs Non-ACL Deficient</th>
<th>Bilateral vs Non-ACL Deficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$</td>
<td>.20</td>
<td>.035</td>
<td>.001</td>
</tr>
</tbody>
</table>

*Abbreviation: ACL, anterior cruciate ligament.*
In the bilateral group vs control group model, a 1° increase in posterior-inferior tibial slope angle (P=.001) increased the odds of bilateral knee injury by 34% (OR, 1.34; 95% CI, 1.13-1.60). Age was a significant (P=.025) predictor of ACL injury (OR, 1.05; 95% CI, 1.01-1.09), and a 1-year increase in age was associated with a 5% increase in the odds of bilateral knee injury. Compared with the group with low Tegner activity, the group with high Tegner activity had a statistically significant (P=.008) 8-fold increase in the odds of bilateral injury (OR, 8.1; 95% CI, 1.7-38.7). The group with midlevel Tegner activity was not significantly different (P=.082) from the group with low Tegner activity (OR, 3.7; 95% CI, 0.84-16.2).

**Discussion**

The current findings showed a significant difference in posterior-inferior tibial slope angle between the group with bilateral ACL injury and the control group without ACL deficiency as well as between the group with unilateral ACL injury and the group without ACL deficiency. Cadaveric biomechanical studies have shown that changes in the anatomy of the proximal tibia affect biomechanical changes across the knee joint. These forces are particularly evident with axial loading. McLean et al. used a cadaveric biomechanical study to show that, for each 1° increase in posterior-inferior tibial slope angle, there is an associated 1.11-m/sec² increase in anterior tibial translation and a 0.6% increase in relative ACL strain on the anteromedial bundle. Dejour and Bonnin used a prospective case model to show that, for each 10° increase in posterior-inferior tibial slope angle, a 6-mm increase in tibial translation with axial loading occurred. Shelburne et al. showed that a 5° increase in posterior-inferior tibial slope angle led to a 30% increase in shear force across the tibia.

Recent clinical studies attempted to quantify risk analysis associated with increased posterior-inferior tibial slope angle. Beynon et al. evaluated 88 athletes with noncontact ACL injuries and concluded that, for each 1° increase in posterior-inferior tibial slope angle, there is an associated 21.7% increase in the risk of noncontact ACL injury. In 2013, Webb et al. evaluated posterior tibial slope in relation to failure of ACL reconstruction and contralateral ACL rupture. Their study found that patients with a posterior-inferior tibial slope angle of greater than 12° had a 59% failure rate at 15 years and a 5-fold increase in the risk of failure. A meta-analysis of 14 studies of posterior-inferior tibial slope and ACL injury by Wordeman et al. reviewed studies of medial and laterally based posterior-inferior tibial slope angle as well as measurements based on magnetic resonance imaging and radiography. Their study found wide variation in study design, method of angle measurement, and conclusions. No conclusion could be made for a specific threshold or at-risk value for posterior-inferior tibial slope angle.

The authors believe that there is a significant increase in the risk of noncontact ACL injury in patients with increasing posterior-inferior tibial slope angle. In this population, there are few modifiable factors. Posterior-inferior tibial slope angle can be decreased with a tibial osteotomy, and native knee biomechanics can be optimized with a regimen of physical strength training and rehabilitation.

Historically, posterior-inferior tibial slope has been considered a nonmodifiable risk factor for ACL injury; however, high tibial osteotomy may have a role in certain patients with a posterior-inferior tibial slope greater than a certain threshold. Several canine studies evaluated a joint leveling procedure at the time of surgery for ACL deficiency. After joint leveling osteotomy, the animals showed significantly less anterior tibial translation with axial loading. This adjunct carries greater associated morbidity compared with the procedure without the joint leveling component, and more research is needed before this approach can be recommended as an addition to ACL reconstruction.

Patients with increased posterior-inferior tibial slope angle have inherently increased anterior tibial translation and increased ACL strain with axial loading. Previous studies showed a decrease in noncontact ACL injuries in patients actively involved in specific physical and proprioceptive training programs. Boden et al. showed that changes in tibiofemoral alignment with positioning of the joint space are associated with changes in force across the knee joint. Additionally, landing mechanics, neuromuscular training, and lower extremity strength decrease the risk of noncontact ACL injury in soccer players. In this at-risk population, identifying potential modifiable risk factors could help to decrease the risk of noncontact ACL injury.

**Conclusion**

There has been much debate over the significance of posterior-inferior tibial slope angle, the measurement of this angle, and quantification of the risk of injury. Unlike previous studies, the current study evaluated the native knee in patients with bilateral ACL injury. This eliminates differences introduced with reconstruction techniques, graft choices, or other surgically specific variables that would create bias in a unilateral outcome study. The current findings showed an association between posterior-inferior tibial slope angle in a group of patients with bilateral noncontact ACL injury compared with a group of patients with unilateral noncontact ACL injury and a group of patients without ACL deficiency. In the group with bilateral ACL injury, the posterior-inferior tibial slope angle was statistically significantly increased compared with the patients in both the group with unilateral ACL injury and the control group without ACL deficiency. There is a noted 34% increase in risk of noncontact bilateral ACL injury for each 1° increase in posterior-
inferior tibial slope compared with the group of patients without ACL deficiency and a 20% increased risk compared with the group with unilateral ACL injury.

REFERENCES