Biomechanical Analysis of Knee Laxity With Isolated Anteromedial or Posterolateral Bundle—Deficient Anterior Cruciate Ligament

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Purpose: The purpose of this study was to clarify the changes in the kinematics of the knee that result from isolated deficiency of the anteromedial (AM) or posterolateral (PL) bundle. Methods: Fourteen cadaveric knees were mounted in a 6-df rig and tested using the following 5 loading conditions: 90-N anterior and posterior tibial loads, 5-Nm internal and external tibial torques, and a simulated pivot-shift test. Tibiofemoral kinematics during flexion-extension was recorded with an optical tracking system for (1) intact knees, (2) knees in which the isolated AM bundle was cut, (3) knees in which the isolated PL bundle was cut, and (4) anterior cruciate ligament (ACL)—deficient knees. The distances between the femoral and tibial attachments of the AM and PL bundles of the ACL were also calculated. Results: Anterior translation laxity under an anterior tibial load, rotational laxity under an internal tibial torque, and anterior translation laxity under pivot-shift loading were significantly different between the knees with AM and PL bundle deficiencies (P < .024), but the changes were small: less than 3 mm or 1.5°. The AM bundle distance increased significantly more after an AM bundle tear (P = .004) than after a PL bundle tear in flexion. Cutting the PL bundle did not have a significant effect on the lengths between the bundle attachments. Conclusions: An isolated AM or PL bundle tear caused a small increase in laxity (<3 mm or <1.5°). Clinical Relevance: If there is a clinically identifiable increase in laxity, then—in addition to the isolated tear of the AM or PL bundle—there must also be a tear of the other bundle of the ACL, or at least a partial tear.

The normal anterior cruciate ligament (ACL) consists of 2 fiber bundles: the anteromedial (AM) and posterolateral (PL) bundles. Recently, a few studies have reported the clinical results of selected 1-bundle reconstruction, preserving the “intact” bundle. However, these studies did not describe how to clinically diagnose the isolated AM or PL bundle tear. With the clinically available tools and techniques, it is unclear whether an isolated AM or PL bundle tear can be diagnosed accurately or consistently. Some authors have noted that not only is the definition of “partial rupture” controversial but, even with extensive clinical examination and imaging, a diagnosis may only be confirmed arthroscopically. Consequently, the clinical entity of an isolated AM or PL bundle tear has not been established as of yet. To establish how to diagnose the isolated AM or PL bundle tear, it is necessary to increase our fundamental database on kinematics of the knee with an isolated AM or PL bundle injury in comparison with kinematics of the normal knee, as well as that of a completely ACL-deficient knee.

Many studies have reported on changes of in situ tension or length of the intact AM and PL bundles during knee motion under various biomechanical conditions. However, although these studies can indicate which of the fiber bundles is tense at each angle of knee flexion, they cannot provide clinicians with direct information on the abnormal tibial translation and/or rotation that will occur as a result of an
isolated AM or PL bundle injury under clinically available manual tests. Only a few studies have reported kinematic information that contributes directly to our knowledge of clinical manual tests. Furman et al. applied loads by hand and found a clear difference between the effects of cutting each bundle: isolated AM bundle cutting allowed increased anterior translation in the flexed knee but not in extension, whereas the reverse was found when the isolated PL bundle was cut. Zantop et al. reported that isolated transection of the PL bundle significantly increased anterior tibial translation at 30° whereas transection of the AM bundle significantly increased the translation at 60° and 90°. However, Hole et al. found that isolated transection of the PL bundle did not increase the anterior translation significantly at 30°. Thus there were conflicting conclusions among the previous studies. In addition, although one previous study analyzed kinematics of the knee with an isolated AM or PL bundle injury under a combined rotatory load at fixed angles of knee flexion, no studies have investigated knee kinematics under the mechanical conditions that simulate the dynamic clinical pivot-shift test, in which the knee is flexing-extending and tension in the iliotibial tract is needed. Therefore the diagnosis of partial tears of the ACL continues to be difficult, and thus there is still a need to increase the database on the kinematics of the knee with an isolated AM or PL bundle injury under various biomechanical conditions in comparison with those of the normal knee.

The purpose of this study was to clarify the changes in the kinematics of the knee that result from isolated deficiency of the AM or PL bundle. We hypothesized that there would be significant differences between the knee laxity changes for each bundle, which would allow a differential diagnosis of isolated bundle ruptures.

**Methods**

**Specimen Preparation**

Fourteen fresh-frozen cadaveric right knees (mean age, 61 years; range, 31 to 72 years) were obtained with consent and permission from the Riverside Research Ethics Committee (London, England). The knees were stored at −20°C and thawed 1 day before experimentation. Each knee was prepared on 1 day and kept overnight in a refrigerator, and the kinematic experiment for that knee was completed the following day. The femur and tibia were cut approximately 200 mm from the joint line, and the soft tissues more than 100 mm away from the joint line were removed. The iliotibial band was preserved. The fibular head was transfixed to the tibia by 2 screws to maintain its anatomic position. We cemented 400-mm-long, 10-mm-diameter aluminum intramedullary rods 150 mm deep into the femur and tibia, aligned to the anatomic axis by use of an outrigger alignment rod. The femoral end was cemented in a steel sleeve aligned coaxial with the tibial intramedullary rod while the knee was held at 0° of flexion. This minimized the varus-valgus moment during passive flexion-extension.

The femoral steel sleeve was secured in a rig that allowed manual passive knee flexion-extension by moving the femur while the tibia hung vertically below it; the motion of the hanging tibia was otherwise unconstrained (Fig 1). A Steinmann pin was drilled mediolaterally across the proximal tibia perpendicular to the shaft, and 2 semicircular hoops were mounted on this, one anterior and one posterior. These could be connected to weights by pulleys and strings to impose an anterior or posterior tibial drawer force without inhibiting coupled rotation. A polyethylene disk (diameter, 200 mm) was secured to the distal end of the tibial rod. Weights connected by pulleys and strings to opposite poles of the disk produced an internal or external rotation torque (Fig 1).

**Tracking System**

The kinematics of the tibiofemoral joint was measured dynamically with a Polaris stereo optical system (Northern Digital, Waterloo, Canada) with Traxtal active optical trackers (Traxtal, Toronto, Canada), each with a mean accuracy of ±0.03° and ±0.04 mm, mounted on the tibia and femur (Fig 1). A 4.5-mm bicortical rod was inserted into the diaphyseal area of each femur and tibia by use of a power driver, placed off-center to avoid the intramedullary rod, and final optimal tightening was achieved manually. Then, specially designed tracker-holding devices were attached to these rods. Landmarks were digitized with an optical stylus that was tracked by the Polaris system to construct the coordinate systems for the femur and tibia. The femoral coordinate system used the anatomic axis of the intramedullary rod and a transverse axis from the sulcus of the medial epicondyle to the apex of the lateral epicondyle, which was exposed through small incisions. The tibial coordinate system used the intramedullary axis and the most medial and lateral points of the plateau. The raw kinematic data were processed with Visual3D software (C-Motion, Germantown, MD). Flexion-extension was defined as rotation about the femoral transepicondylar axis and internal rotation—external rotation about the long axis of the tibia. Zero degrees of knee flexion was defined when the tibial and femoral intramedullary rods were parallel in the sagittal plane. The software determined the anteroposterior translation by calculating the anteroposterior distance of the tibial reference plane relative to the midpoint of the transepicondylar line.

The motion of the tibia with respect to the femur was recorded with no external loads applied while the knee
was intact. Thus the only loading was the weight of the tibia, plus the intramedullary rod and pulley, which hung vertically below the distal femur. The femur was flexed-extended in the test rig above the hanging tibia, which was free to float in the other 5 df, such as anteroposterior translation and internal rotation—external rotation (Fig 1B). These tibiofemoral relative motions were not inhibited or altered by the test rig.23-25

Testing Protocol
The intact knee was moved from full extension to 110° of knee flexion and then back to extension for 3 cycles; that is, flexing the femur from vertical, down through horizontal, and then back up to vertical while the tibia remained vertical below the knee. Then, each of the following loads was applied to the tibia: (1) 90-N anterior drawer force, (2) 90-N posterior drawer force, (3) 5-Nm internal rotation torque, (4) 5-Nm external rotation torque, and (5) simulated pivot-shift test. The pivot-shift test was simulated by use of a 50-N iliotibial band tension, 5-Nm valgus moment, and 1-Nm internal rotation torque.21,22,25 A nylon cable secured to the iliotibial band was attached to a precalibrated pneumatic cylinder alongside the femur to generate the 50-N tension.22,25

After all 14 intact knees were tested, an isolated failure of the AM or PL bundle was simulated by arthroscopic transection through a mini-arthrotomy. The overlying synovium around the ACL was removed to expose the surface fibrous structure of the ACL. Next, the AM and PL bundles of the ACL were identified and separated by a blunt probe between them (Fig 2A). The 14 knees were separated into 2 groups: In 7 specimens the AM bundle was transected first at the midsubstance to simulate an isolated AM bundle tear (Fig 2B). In the remaining 7 specimens, the PL bundle was transected at the midsubstance to simulate an isolated PL bundle tear. Knee kinematic measurements were repeated for the isolated AM or PL bundle tear. Then, the remaining bundle was transected arthroscopically (Fig 2C), and the kinematics of the ACL-deficient knee was measured in all 14 knees with the 5 external loading conditions described earlier. The midsubstance of the AM and PL bundles of the ACL was sharply resected with a knife, leaving 1-mm-long ligament tissues at the femoral and tibial attachments. The centers of the femoral and tibial attachments of the AM and PL bundles were marked with ink and were digitized with an optical stylus to calculate the distances between the femoral and tibial attachments of the AM and PL bundles. Data were calculated from the processed kinematic data with Visual3D software.

Statistical Analysis
An a priori power analysis was performed based on preliminary data comparing isolated deficiency of the AM and PL bundle of the ACL. A sample size was calculated to have 74.6% to 95.1% power to test the hypothesis with 95% confidence with 7 or 14 knees in each group (α level of .05). The kinematic data were analyzed by a 2-factor analysis of variance (ANOVA) (StatView; SAS Institute, Cary, NC). The 2 factors evaluated were the condition of the ACL (intact, 1 bundle cut, and ACL deficient) and knee flexion angle. Although the kinematic data were treated as continuous data, they were analyzed and presented
graphically at 5° increments of knee flexion. The outcomes (dependent variables) were anterior and posterior translation laxities, internal and external rotation laxities, anterior translation and internal rotation in response to pivot-shift loading, and distances between the femoral and tibial attachments of each AM and PL bundle. For each of the dependent variables, 2-way interactions between the group outcome and knee flexion were examined; differences between the laxities in the 3 conditions of the knee were evaluated at each angle of knee flexion by the Bonferroni-Dunn test at each 5° increment of knee flexion. The significance level was set at \( \alpha = .05 \), so \( P < .0167 \) was considered statistically significant for a 3-way comparison.

**Results**

**Kinematics of Normal Knee**

The laxities measured when the knees were intact were in line with previously published data (Table 1). For example, at 30° of knee flexion, anterior translation was 4.0 ± 1.3 mm; posterior translation, 4.4 ± 1.8 mm; internal rotation, 21.8° ± 7.8°; and external rotation, 18.1° ± 6.0°. Rather than present normal laxity data, this article presents the changes from normal, which yields greater clarity regarding the effects of cutting the fiber bundles.

**Kinematics of ACL-Injured Knees**

**Anterior Translation Under 90-N Anterior Load.** Under a 90-N anterior load, ANOVA showed that there were significant differences in anterior translation laxity among the groups of ACL-deficient knees and knees with AM and PL bundle tears (\( P < .001 \)) and that there were significant interactions with knee flexion (\( P = .012 \)) (Fig 3). Post hoc testing found that cutting the AM bundle alone did not increase the anterior translation significantly from 0° to 110° of knee flexion in comparison with the normal translation (\( P = .998 \) at 0° to \( P = .078 \) at 110°). The maximal increment caused by cutting the AM bundle was 3.7 mm, at 95° of knee flexion (\( P = .075 \)) (Fig 3). Similarly, cutting the PL bundle alone did not increase the anterior translation significantly at 0° to 110° of knee flexion in comparison with the normal translation (\( P = .552 \) to \( P = .982 \) (Fig 3). After both bundles were cut, the anterior tibial translation increased at each angle of knee flexion in comparison with the normal translation; this was significant from 0° to 100° flexion (\( P < .001 \) to \( P = .007 \)) (Fig 3). The maximal increment caused by cutting both of the bundles was 11 mm, at 30° of knee flexion (\( P < .001 \)) (Fig 3).

Transection of each fiber bundle of the ACL did not cause any measurable changes in tibial posterior translation laxity.

**Tibial Rotation Under 5-Nm Torque.** Under a 5-Nm internal rotation torque, ANOVA found significant differences in tibial internal rotation laxity between the knees with partial ACL cutting and the ACL-deficient state (\( P < .001 \)); there were also significant interactions with knee flexion (\( P < .001 \)) (Fig 4). The maximal increase in internal rotation was 1.2° by cutting either the AM or PL bundle alone, at 25° and

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**Table 1. Mean Laxity of Intact Knee Relative to “No Load” Position (N = 14)**

<table>
<thead>
<tr>
<th></th>
<th>Knee Flexion Angle of 0°</th>
<th>Knee Flexion Angle of 30°</th>
<th>Knee Flexion Angle of 60°</th>
<th>Knee Flexion Angle of 90°</th>
<th>Knee Flexion Angle of 110°</th>
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<tbody>
<tr>
<td>Anterior translation (mm)</td>
<td>1.8 (1.3)</td>
<td>4.0 (1.3)</td>
<td>3.8 (2.2)</td>
<td>3.0 (1.4)</td>
<td>2.9 (1.7)</td>
</tr>
<tr>
<td>Posterior translation (mm)</td>
<td>3.0 (1.6)</td>
<td>4.4 (1.8)</td>
<td>2.9 (1.4)</td>
<td>3.5 (1.7)</td>
<td>4.4 (1.9)</td>
</tr>
<tr>
<td>Internal rotation (°)</td>
<td>10.4 (7.1)</td>
<td>21.6 (7.8)</td>
<td>22.7 (6.8)</td>
<td>21.9 (7.0)</td>
<td>22.6 (7.5)</td>
</tr>
<tr>
<td>External rotation (°)</td>
<td>8.9 (6.9)</td>
<td>18.1 (6.0)</td>
<td>19.4 (4.8)</td>
<td>19.6 (4.8)</td>
<td>19.7 (5.1)</td>
</tr>
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*NOTE. Data are presented as mean (standard deviation). *

*Under 90-N anterior tibial load.

*Under 90-N posterior tibial load.

*Under 5-Nm internal tibial load.

*Under 5-Nm external tibial load.

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**Fig 2.** (A) Arthroscopic finding of intact ACL, (B) AM bundle cut, and (C) complete ACL cut.
80° of knee flexion ($P \geq .330$ and $P \geq .218$, respectively) (Fig 4). After both bundles were cut, the pathologic increase in tibial rotation increased toward the extended posture, reaching 3.8° in extension (Fig 4). Post hoc testing showed that cutting both the AM and PL bundles significantly increased the tibial internal rotation near knee extension in comparison with AM bundle–deficient laxity ($P \leq .014$ at 0° to 30° of flexion), as well as in relation to PL bundle deficiency ($P \leq .006$ at 0° to 55° of flexion) (Fig 4).

Under a 5-Nm external rotation torque, ANOVA did not show significant differences between the ACL-deficient knees and the knees with AM and PL bundle tears.

Anterior Translation and Internal Rotation Under Simulated Pivot-Shift Loading. Under simulated pivot-shift loading, ANOVA indicated that there were significant differences in tibial anterior translation among the ACL-deficient knees, knees with isolated AM bundle deficiency, and knees with isolated PL bundle deficiency ($P < .001$) (Fig 5). There were also significant interactions between anterior laxity and the angle of knee flexion ($P < .001$). Post hoc testing did not show that cutting either the AM bundle ($P \leq .242$) or PL bundle ($P \leq .305$) in isolation increased the anterior translation significantly at any angle of knee flexion in comparison with the anterior translation during the pivot-shift test when the ACL was intact (Fig 5). After both bundles were cut, the anterior tibial translation increased significantly ($P < .001$) at 0° and 15° of knee flexion (Fig 5), reaching 3 mm at 10° of knee flexion.

On the other hand, transection of the ACL did not cause a significant change in tibial internal rotation during the simulated pivot-shift test.

Distance Between Femoral and Tibial Attachments of AM or PL Bundle
When the knee was flexed from 0° to 110° without loads applied to the tibia, the distance between the femoral and tibial attachments of the AM bundle was almost constant, at approximately 35 mm, whereas the distance of the PL bundle decreased from 30 mm to 24 mm ($P < .001$) (Fig 6). Under the 90-N anterior tibial load, the AM bundle remained isometric when the ACL was intact, with a mean length between its attachments of 38 mm (Fig 7A), whereas the distance between the PL bundle attachments was reduced from 31 mm in the extended knee to 25 mm at 90° of knee flexion (Fig 7B).

Cutting the AM bundle in isolation had no effect on the lengths when the knee was extended under 30° of knee flexion ($P > .538$), but the anterior drawer force caused both the AM and PL bundle attachments to move apart by a mean of 3 mm at 90° of knee flexion ($P = .112$). Cutting the PL bundle in isolation had no measurable effect on the lengths between the bundle attachments at any angle of knee flexion ($P > .605$). In the ACL-deficient knees, the lengths between the bundle attachments under the 90-N anterior drawer force were significantly greater than those in the intact knees at all flexion angles ($P < .012$ at 0° and $P < .001$ at 10° to 110°). This effect was largest at 30° of flexion.
with a mean increase of 8 mm (Fig 7). The lengths between the bundle attachments were greater with ACL deficiency than with either of the bundles cut: $P < .043$ with the AM bundle cut from 0° to 85° of flexion and $P < .018$ with the PL bundle cut from 5° to 110°. This effect was clearer under anterior translation force ($P < .001$ from 5° to 110° of knee flexion for each bundle).

**Discussion**

There are several patterns of partial or complete rupture of the ACL.9,20 Many clinical studies have been conducted on partial ACL injury.26-30 In these studies, however, the definition of the partial ACL injury has been unclear. The studies appeared to include not only knees in which one bundle was torn and the other was intact (isolated PL or AM bundle tear) but also various types of ACL injury; for example, they involved knees in which one bundle was torn and the other was permanently elongated or knees in which both bundles were permanently elongated. This history has resulted in the current confusion in the clinical field, and the diagnosis of a partial ACL tear is a controversial issue.5,7,20 In our study we dealt with isolated AM or PL bundle deficiency, in which one bundle was transected and the other was intact and was not permanently elongated. We sought to distinguish the isolated AM or PL bundle tear from the other types of partial ACL injury.

This study has provided data on changes in knee laxity and kinematics with an isolated AM or PL bundle injury, not only under a pure anterior drawer force or internal or external rotation torque but also under simulated pivot-shift loading. With the 5-Nm internal rotation torque, cutting either the AM or PL bundle did not increase the tibial rotation at each angle of knee flexion in comparison with normal rotation. Under pivot-shift loading, cutting either the AM or PL bundle alone did not lead to a significant increase in tibial anterior translation; this was found only after transection of the whole ACL. When Zantop et al.19 applied a combined rotatory load of 10 Nm of valgus moment and 4 Nm of internal torque at a fixed angle of knee flexion without any loads on the iliotibial band, transection of the AM bundle did not significantly increase coupled anterior translation whereas transection of the PL bundle significantly increased anterior translation at 0° and 30° of knee flexion. Although the effect of AM bundle transection was similar between the 2 studies, the effect of PL bundle transection was different. The difference is considered to be due to differences in the loading conditions: in addition to the differing moments and iliotibial band tension applied, when the pivot shift occurs in the moving knee, the instant axis of rotation will differ from that which occurs at a fixed angle of flexion.

Moreover, our study provided important information on anterior tibial translation under a 90-N anterior load to solve the previously described controversy that has
were applied under biomechanical conditions similar to the clinical test. Under these testing conditions, it is considered that the effect of isolated PL bundle transection was not significantly detected because the intact AM bundle remained relatively tight (i.e., at a constant length) during knee motion. The differences in the effect of isolated PL bundle transection among the studies may be a result of the differences in the testing conditions. In general, application of larger loads will magnify any changes in laxity, but a judgment must be made in repeated-measures studies because the loads must be small enough that they will not cause permanent deformations of the remaining ligament bundles.

As to clinical relevance, our study has provided important information on the clinical diagnosis of an isolated AM or PL bundle tear using manual tests such as the Lachman, anterior drawer, and pivot-shift tests, as well as noninvasive measurement devices such as the KT-2000 arthrometer (MEDmetric, San Diego, CA). Concerning the isolated PL bundle tear, there were few differences in tibial translation or rotation between the intact knee and the isolated PL bundle—deficient knee under any loading condition. These results suggest that it is impossible to clinically diagnose an isolated PL bundle tear. Hole et al. reported that only 11% of the examinations correctly diagnosed the isolated PL bundle resection, although the examiners were accurate in their interpretation of the status of the ACL in 89% of the intact specimens and 80% of completely sectioned ACLs. Clinical evaluation is accurate in defining intact and completely sectioned ACLs. However, it is unable to differentiate a sectioned PL bundle from an intact ACL. This suggests that a clinical diagnosis of a partial tear of the ACL that includes only the PL bundle may also involve stretching of the AM bundle. Some authors noted that, even with extensive clinical and imaging assessment, the exact injury pattern of an isolated bundle tear might only be established arthroscopically. The evidence from this study suggests that surgeons who are performing “partial ACL reconstructions” of 1 fiber bundle or the other as a result of clinically identified increases in knee laxity are actually also treating a knee in which the remaining fiber bundle has undergone permanent elongation.

Regarding the isolated AM bundle tear, there was only a tendency for the tibial translation under the anterior force to increase toward 90° of knee flexion in comparison with the normal knee, and there were no differences under simulated pivot-shift test loading. Zantop et al. did find a significant increase in the flexed knee under a larger force. Therefore it is theoretically possible to clinically diagnose an isolated AM bundle tear using the anterior drawer test. However, the maximal increment by cutting the AM bundle was only 3 mm and 1.5°. Therefore, these facts imply that it existed in the clinical field of ACL injury. Namely, under the 90-N anterior load, cutting either the PL or AM bundle alone did not increase tibial anterior translation significantly, with the largest mean change (4 mm, \( P = .075 \)) occurring after cutting the AM bundle at 95° of knee flexion. Cutting both the AM and PL bundles dramatically increased anterior translation or rotation not only under the 90-N anterior load but also under pivot-shift loading and the 5-Nm internal torque. Hole et al. reported that sectioning the PL bundle alone did not significantly increase anterior translation at 30° under a 133-N anterior load, as well as that a significant increase was found after sectioning both the PL bundle and half of the AM bundle. Recently, however, Zantop et al. reported that when a 134-N anterior load was applied to the tibia at 30°, 60°, and 90° of knee flexion, isolated transection of the PL bundle significantly increased anterior tibial translation at 30°. Our study supported the results reported by Hole et al. Concerning the effect of AM bundle transection, however, our study supported the results of Zantop et al., who reported that transection of the AM bundle alone significantly increased the translation at 60° and 90° when the robotic system in their study applied 134 N. In the study by Hole et al. and our study, loads of 133 and 90 N
may be difficult for common orthopaedic surgeons to always detect the abnormal laxity of the isolated AM bundle tear only using the manual tests. Previously, Lintner et al. sectioned the AM bundle of the ACL and found that clinical examination and KT-1000 arthrometer testing (MEDmetric) were unable to detect differences from the intact knee because the small (1.3-mm) increase in anterior translation that occurred was within the 2-mm normal bound of side-to-side differences. On the other hand, the tibial translation and rotation were dramatically increased by cutting both the AM and PL bundles. This fact indicated that the knee with obviously abnormal translation and rotation of the tibia and positive pivot-shift phenomenon in comparison with the normal knee should be strongly suspected of having a complete tear of the 2 bundles.

In this study the change in the distance between both attachment sites was calculated. In the ACL-deficient knee, the lengths between the bundle attachments under the 90-N anterior drawer force were significantly greater than those in the intact knee at all flexion angles. The AM bundle tear had no effect on the lengths when the knee was extended, but the anterior drawer force caused both the AM and PL bundle attachments to move apart by a mean of 3 mm at 90° of knee flexion. The PL bundle tear had no measureable effect on the lengths between the bundle attachments at any angle of knee flexion. These data show that, whichever bundle was cut, the remaining bundle continued to restrain the excursions between the attachments close to normal, matching the nonsignificant changes in laxity. Although our study and other studies have concluded that the effects on knee laxity of individual ACL fiber bundle deficiencies are so small that they may be difficult to detect in response to the small loads imposed clinically, that is not the same as knowing that partial ACL ruptures (of one fiber bundle or the other) will not cause instability symptoms during functional dynamic activities with higher loads. However, the small changes in kinematics during the simulated pivot-shift tests in this study are in line with the conclusion of several reports that a partial tear of the ACL has a negative pivot shift or only a trace of a pivot shift.

Limitations

In this study the kinematics of 14 human cadaveric knees was evaluated quantitatively with an optical tracking system in a 6-df test rig. This method had the benefit of collecting data from the same specimen under different experimental conditions (intact, partially ACL deficient, and ACL deficient), thus eliminating interspecimen variation by repeated-measures statistical analyses. The kinematics of the intact knee in this study was consistent with previous work. However, this experiment inevitably suffered the drawbacks associated with work on elderly specimens in vitro. Given that younger patients would have stronger and/or stiffer ACLs, the small laxity changes found in this study in response to partial ACL deficiency would be even smaller and more difficult to find clinically. Furthermore, the conclusions reached refer to time-zero conditions and may be influenced subsequently by the effects of a chronic tear of the AM or PL bundle of the ACL. These limitations have been offset by the ability to perform a series of comparative intraspecimen tests on a range of partial ACL deficiencies. Furthermore, the test setup allowed carefully controlled loads to be applied and full 6-df kinematic deficiencies. It has been shown that anteroposterior laxity measurements in vitro duplicate clinical laxity tests of the passive ligament restraints, but there is a lack of knowledge about clinical rotational laxity. Another limitation is that, because the straight-line distances between the femoral and tibial attachments of the AM or PL bundles were calculated, they were not real AM or PL bundle lengths but were only the distances separating the bone attachments. The relatively simple external loading conditions used in this study could only simulate those used in clinical examinations. To more accurately mimic in vivo loading conditions, larger forces such as those from the quadriceps and hamstring muscles will be needed.

Conclusions

An isolated AM or PL bundle tear caused a small increase in laxity (<3 mm or <1.5°). If there is a clinically identifiable increase in laxity, then—in addition to the isolated tear of the AM or PL bundle—there must also be a tear of the other bundle of the ACL, or at least a partial tear.

References


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