The role of the posterolateral and cruciate ligaments in the stability of the human knee. A biomechanical study

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The Role of the Posterolateral and Cruciate Ligaments in the Stability of the Human Knee

A BIOMECHANICAL STUDY*

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ABSTRACT: Injury to the posterolateral structures of the knee, including the popliteus tendon and arcuate complex, frequently results in poorly understood patterns of instability. To evaluate the static function of these tissues, we used a mechanical testing apparatus that allowed five degrees of freedom to test seventeen specimens from human cadavera at angles of flexion that ranged from zero to 90 degrees. Selective section of the lateral collateral ligament, popliteus-arcuate (deep) ligament complex, anterior cruciate ligament, and posterior cruciate ligament was performed.

At all angles of flexion, the lateral collateral ligament and deep ligament complex functioned together as the principal structures preventing varus rotation and external rotation of the tibia, while the posterior cruciate ligament was the principal structure preventing posterior translation. However, at angles of flexion of 30 degrees or less, the amount of posterior translation after section of only the lateral collateral ligament and the deep structures was similar to that noted after isolated section of the posterior cruciate ligament. Isolated section of the posterior cruciate ligament did not affect varus or external rotation of the tibia at any position of flexion of the knee.

When the posterior cruciate ligament was sectioned after the lateral collateral ligament and deep ligament complex had been cut, a large increase in posterior translation and varus rotation resulted at all angles of flexion. In addition, at angles of flexion of more than 30 degrees, external rotation of the tibia also increased.

The application of internal tibial torque resulted in no increase in tibial rotation after isolated section of the anterior cruciate ligament or combined section of the lateral collateral ligament and deep ligament complex. However, combined section of all three structures increased internal rotation at 30 and 60 degrees of flexion. The increases in external rotation that were produced by section of the lateral collateral ligament and deep ligament complex were not changed by the addition of the section of the anterior cruciate ligament.

CLINICAL RELEVANCE: Our results demonstrate the importance of the posterolateral ligaments in the prevention of posterior translation, varus rotation, and external rotation of the tibia. They also may help to explain the wide variability of function of the knee in patients who have injured the anterior or the posterior cruciate ligament. Since the posterior cruciate ligament appears to be most functional at greater angles of flexion, patients who have an isolated injury of that ligament may maintain fairly good function of the knee in positions that are closer to extension. Conversely, in patients who have a combined injury of the posterolateral and posterior cruciate ligaments, the knee may be unstable at zero and 30 degrees, and function may be impaired in these positions. Additionally, injury of the anterior cruciate ligament, together with damage to the posterolateral ligaments, may allow enough increased internal and external rotation of the tibia to further compromise the function of the knee.

Static stability of the knee and normal motion of the joint both depend on complex interactions between the surrounding ligaments. In the past, the function of the ligaments

* No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article. Funds were received in total or partial support of the research or clinical study presented in this article. The funding source was the Clark Foundation.

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has been ascertained either by the correlation of findings at surgery with those from the preoperative examination or by biomechanical testing of cadavera[1-28]. Recently, *in vivo* biomechanical testing has been used to study various injuries of the ligaments of the knee; however, this method is limited by a need for enough comparable, documentable injuries to allow statistical evaluation[21]. Since we are frequently unable to judge the full extent of injury to a specific ligament through manual examination or surgical exposure, and since the results of *in vivo* testing are not sufficiently reliable for combined injuries, *in vitro* testing remains indispensable in the study of complex function of the ligaments of the knee.

Our objective in this study was to determine the difference in motion between intact knees and knees that had undergone isolated or combined section of the lateral collateral ligament, popliteus-arcuate (deep) ligament complex, anterior cruciate ligament, and posterior cruciate ligament. A biomechanical knee-testing apparatus was used to apply anterior and posterior tibial force, varus and valgus tibial torque, and internal and external tibial torque to knees from human cadavera at controlled positions of flexion from zero to 90 degrees. During the application of load, five degrees of freedom of motion of the knee (three translations and two rotations) were allowed and recorded.

Materials and Methods

Seventeen knees, including three matched pairs, were obtained at autopsy from seven men and seven women who had ranged in age from thirty-three to seventy-eight years (mean, 61 ± 14 years). The causes of death were neoplastic disease (five), congestive heart failure (three), cerebrovascular accident (two), and myocardial infarction, gastrointestinal hemorrhage, pulmonary failure, and unknown (one each); they were not believed to have affected the experimental results.

The specimens were removed with approximately fifteen centimeters of soft tissue and bone on each side of the joint line and were frozen at −20 degrees Celsius until the evening before preparation, at which time they were removed to thaw in a refrigerator at 5 degrees Celsius. Each specimen was evaluated for damage to the articular cartilage before testing using a roentgenogram and manual manipulation. No specimens were found to have loss of cartilage or crepitation.

Methylmethacrylate was used to secure the specimens in metal fixtures. Care was taken to align the longitudinal axes of the bones with those of the testing fixture. Holes were drilled across the femoral and tibial fixtures through the specimen, and bolts were passed through the holes to prevent slippage. The tibial fixture was attached to a freely rotatable rod and the femoral cup was fixed into a slotted holder that was designed to allow controlled flexion from zero to 90 degrees in 15-degree increments (Fig. 1).

The knee-testing apparatus was mounted on the actuator ram of a servocontrolled hydraulic materials testing system machine. The ram applied an anterior or posterior force to the tibia. Internal and external torque was applied along the longitudinal axis of the tibia using a reversible-torque motor. Varus and valgus torque was applied manually using a torque-handle that was attached to the femoral holder, which resulted in relative femoral rotation about the tibia. Load-cells and torque-cells monitored the applied force and torques, while Shavitz ±1.0-inch (±2.5-centimeter) linear and ±30-degree rotational transducers measured resultant

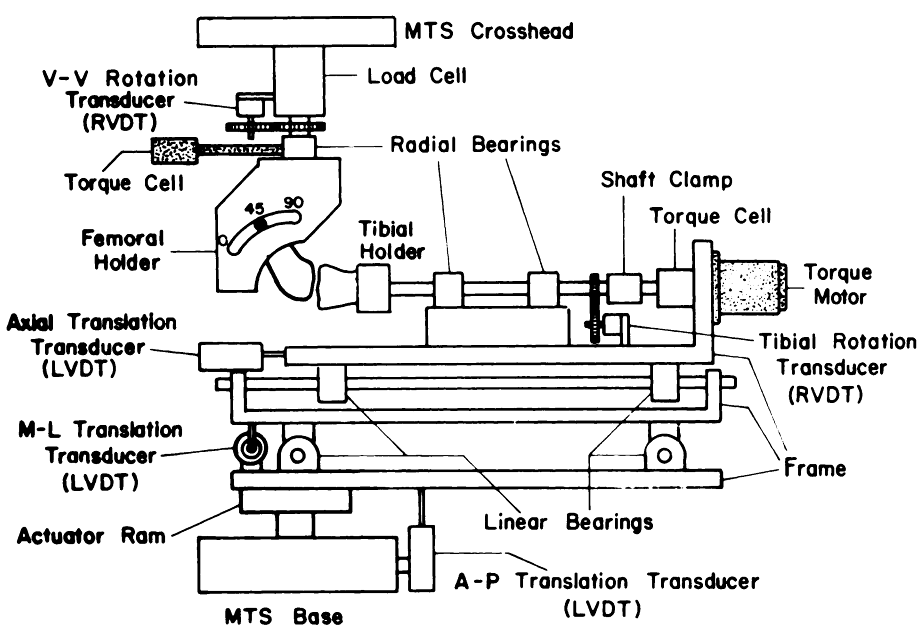

FIG. 1

The apparatus for testing stiffness of the knee mounted on a servocontrolled hydraulic materials testing system machine. Specimens of knees from cadavera are secured in the femoral and tibial holders. Anterior and posterior force was applied manually through the upper left-hand torque-cell, varus and valgus torque was applied by the machine, and internal and external torque was applied by the torque motor. Five degrees of freedom of motion of the knee are allowed by the linear and radial bearings and are measured using the linear and rotational variable-differential transformer transducers.

translations and rotations, respectively. Additional details of the procedure can be found elsewhere[7,19,27].

For each intact specimen, three pre-conditioning cycles were run at each angle of flexion to minimize soft-tissue hysteresis. The inflection point of the resultant curve for anterior and posterior force versus translation (load reversal going from a posterior to an anterior applied force) represented the unconstrained neutral position of the knee with respect to anterior and posterior translation and varus, valgus, internal, and external rotation of the tibia. Transducer readings of the neutral position were recorded at each angle of flexion so the knee could be returned to the neutral position after section of the ligament and before repeating the test.

The following tests were performed on intact knees at 15-degree intervals from zero to 90 degrees of flexion: (1) application of 125-newton anterior and posterior force while monitoring the primary anterior and posterior translation and coupled internal and external rotation of the tibia; (2) application of fifteen newton-meter varus and valgus torque while monitoring the primary varus and valgus rotation, coupled anterior and posterior translation, and coupled internal and external rotation of the tibia; and (3) application of six-newton-meter internal and external tibial torque while monitoring the primary internal and external rotation of the tibia, coupled anterior and posterior translation, coupled varus and valgus rotation, and coupled medial and lateral translation.

Primary motions are defined here as the resultant translation or rotation along or about an axis (line of action) coincident with the axis of an applied force or torque (moment), and coupled motions are those resultant translations and rotations of which the axes are not coincident with the axis of the applied force or torque. While other combinations of coupled motions were recorded, due to insignificant and, at times, inconsistent motions, they provided no useful information for intact knees or those in which one or more ligaments had been sectioned.

The sequences of sectioning of the ligaments are listed in Table I. Section of the discretely palpable lateral collateral ligament was performed through an incision overlying the ligament. The deep section divided the popliteal tendon from the posterolateral capsular structures at the joint line. In the preliminary testing of two knees, the deep tissues were separated into the popliteus tendon and arcuate ligament. Tibial translation increased when the popliteus tendon was sectioned, but no additional increase was seen after section of the posterolateral part of the capsule (arcuate ligament). As a result, no additional combinations of these sections were performed. Section of the anterior and posterior cruciate ligaments was performed through a longitudinal midline posterior capsular incision, which was then sutured closed. Previous testing had shown that these capsular incisions had no effect on motion of the knee[7]. After each ligament was sectioned the test sequence, as outlined already for intact knees, was performed at zero, 30, 60, and 90 degrees of flexion.

For purposes of comparison, values for translations and rotations were chosen at 100 newtons of anteriorly and posteriorly directed force, ten newton-meters of varus and valgus torque, and 4.5 newton-meters of internal and external tibial torque. Data that were derived from a previous study of five specimens in which isolated section of the anterior cruciate ligament was done were included to augment the sample population in order to analyze differences between isolated section of the anterior cruciate ligament and combined section of the lateral collateral ligament, deep ligament complex, and anterior cruciate ligament[8]. These five additional specimens were tested as has already been described and were used only for statistical analysis. Statistical analysis was performed using the Student t test, differences between means and paired-mean differences being considered significant at $p < 0.05$.

Results

Anterior-Posterior Translation with Anterior-Posterior Force

None of the isolated or combined sections produced an increase in anterior tibial translation (Fig. 2-A). As previously reported[7,8,19,27], the greatest anterior translation occurred between 15 and 45 degrees of flexion of the knee.

The specimens in which an isolated section of the posterior cruciate ligament was performed had a significant increase in posterior translation at all angles of flexion as compared with the intact specimens (Figs. 2-A and 2-B). The absolute amount of translation increased progressively from zero to 90 degrees of flexion. Isolated section of the lateral collateral or deep ligament complex produced no increase in translation at any angle of flexion.

Combined section of the lateral collateral ligament and deep ligament complex resulted in small (approximately three-millimeter) but significant increases in posterior translation at all angles of flexion. At zero and 30 degrees of flexion, no significant differences in posterior translation were found between specimens in which isolated section of the posterior cruciate ligament had been performed and those that had undergone combined section of the lateral collateral ligament and deep ligament complex. Combined section of the posterior cruciate ligament, deep structures, and lateral collateral ligament resulted in a significant increase of twenty to twenty-five millimeters in posterior translation at all positions of flexion compared with the intact knee or knees in which isolated section was performed (Fig. 2-B).

Coupled Internal-External Rotation of the Tibia with Anterior-Posterior Force

When anterior force was applied to the tibia of an intact knee, the tibia rotated internally. Similarly, when posterior force was applied, external rotation of the tibia occurred. These predictable resultant tibial rotations are termed coupled rotations[7,8,19,27]. Anterior and posterior force produced a maximum total (internal plus external) tibial rotation of approximately 16 degrees at 60 degrees and 75 degrees of flexion (Figs. 3-A and 3-B). As the knee was extended, the coupled total rotation of the tibia decreased to approximately 5 degrees.

No isolated or combined section of the lateral collateral ligament, deep structures, or posterior cruciate ligament produced an increase in internal rotation with anterior force. When the anterior cruciate ligament was sectioned in addition to the lateral collateral ligament and deep structures, there was a significant increase in coupled internal rotation, but only at 30 degrees of flexion (Fig. 3-A).

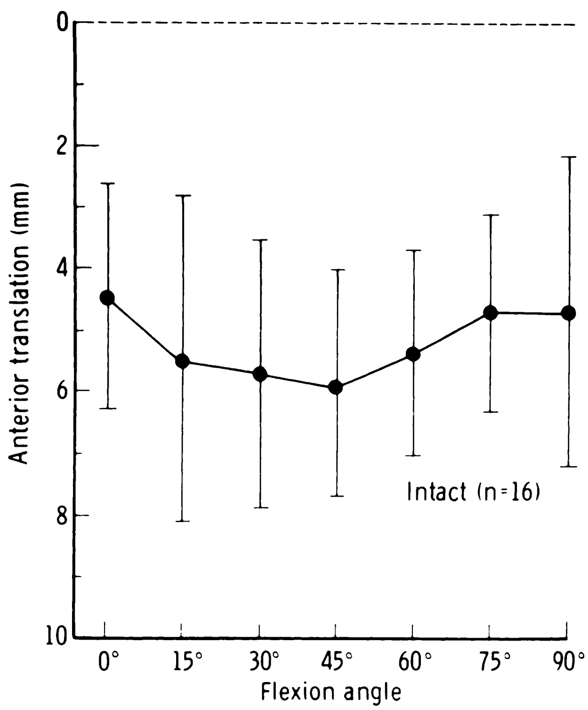

FIG. 2-A

Figs. 2-A and 2-B: Primary anterior and posterior translations resulting from 100 newtons of anterior and posterior force in intact knees and after section of the posterior cruciate ligament (PCL), deep ligament complex, and lateral collateral ligament (LCL).

Fig. 2-A: Anterior tibial translation was not affected by isolated or combined section of the lateral collateral ligament, deep structures, or posterior cruciate ligament. Hence, only the results for intact specimens are shown.

Isolated section of the posterior cruciate ligament eliminated the coupled external rotation that occurred with posterior force but did not affect the coupled internal rotation that occurred with anterior force, which is in accord with previous findings[7,19]. Combined section of the lateral collateral ligament and deep structures significantly increased the external rotation that occurred with posterior force at all angles of flexion, with approximately a 20-degree increase occurring at 30 degrees of flexion of the knee (Fig. 3-B). When the posterior cruciate ligament, lateral collateral ligament, and deep ligament complex were sectioned in combination, there was an increase, but not a significant difference, in the resulting coupled external rotation as compared with the change that was measured when combined section of the lateral collateral ligament and deep ligament complex was performed.

Varus-Valgus Rotation with Varus-Valgus Torque

In the intact knees, the least amount of varus and valgus rotation occurred at full extension (approximately 12 degrees of total rotation), and varus and valgus rotation increased continually with increasing flexion of the knee to 90 degrees (Figs. 4-A and 4-B). Isolated section of the anterior or posterior cruciate ligament produced no significant increase in valgus or varus rotation at any angle of flexion. No isolated or combined section of the lateral collateral ligament, deep structures, or posterior cruciate ligament resulted in any increase in valgus rotation.

As compared with the intact knees, a small but significant increase (1 to 4 degrees) in varus rotation occurred at all angles of flexion when only the lateral collateral ligament was sectioned (seven specimens) and at 90 degrees of flexion when only the deep ligament complex was sectioned (four specimens). A significantly larger increase (5 to 9 degrees) occurred with combined section of the lateral collateral ligament and deep ligament complex, and an even larger increase (14 to 19 degrees) occurred when the posterior cruciate ligament also was sectioned (Fig. 4-B).

Significant increases in varus rotation (5 to 10 degrees) occurred at all angles of flexion when the posterior cruciate

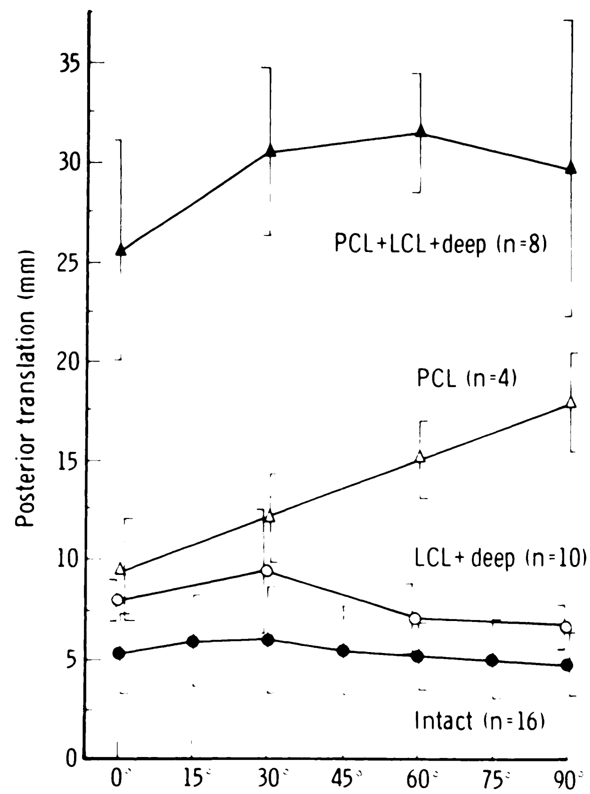

FIG. 2-B

Isolated section of the lateral collateral ligament or deep structures produced no significant change in posterior translation. Compared with intact knees, combined section of the lateral collateral ligament and deep ligament complex and isolated section of the posterior cruciate ligament produced a significant increase in posterior translation at all angles of flexion of the knee. No difference was found between the results of these two types of section at zero and 30 degrees of flexion of the knee.

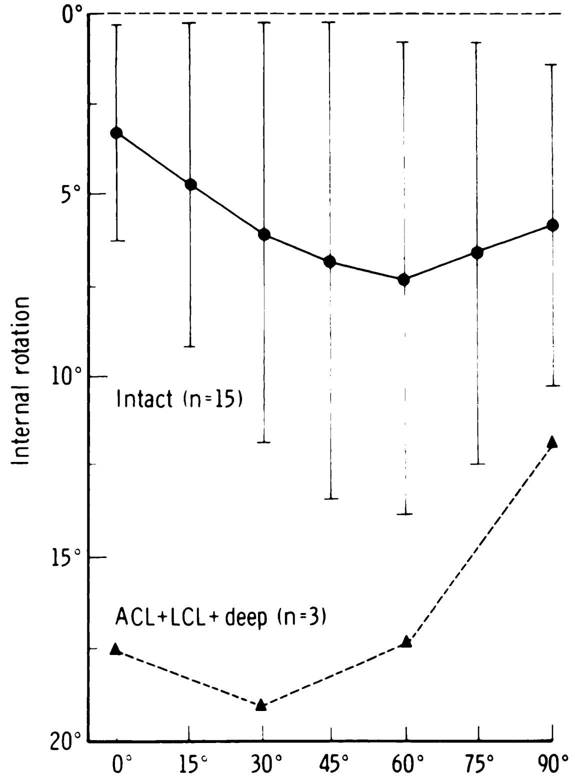

Fig. 3-A

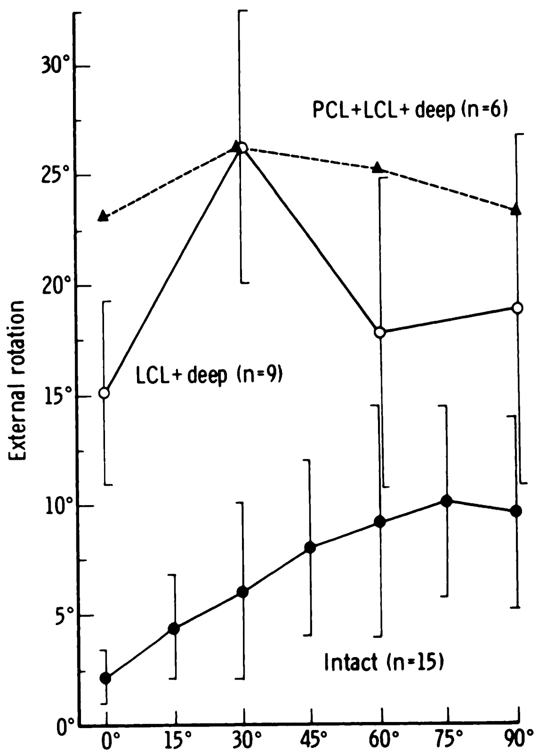

Fig. 3-B

Figs. 3-A and 3-B: Coupled internal and external tibial rotations resulting from 100 newtons of anterior and posterior force in intact knees and after section.

Fig. 3-A: Only combined section of the lateral collateral ligament (LCL), deep structures, and anterior cruciate ligament (ACL) produced a significant increase in internal rotation with anterior force at 30 degrees of flexion of the knee. (Standard deviation was omitted for clarity.)

Fig. 3-B: The increase in external rotation after combined section of the lateral collateral ligament and deep ligament complex was significant at all angles of flexion. It did not increase more ($p > 0.05$) when the posterior cruciate ligament (PCL) was sectioned. The broken lines indicate a lack of statistical difference from the adjacent curve unless otherwise stated.

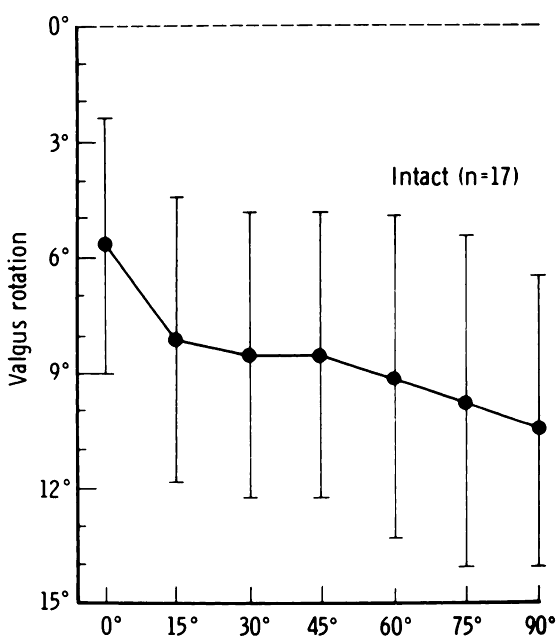

Fig. 4-A

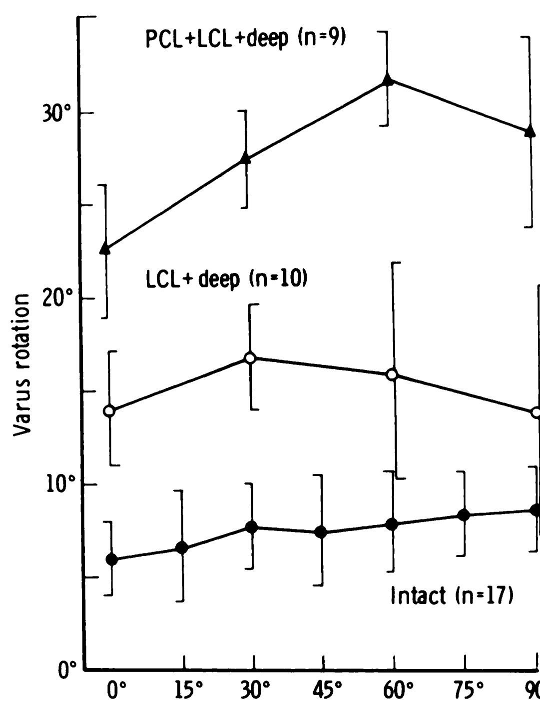

Fig. 4-B

Figs. 4-A and 4-B: Primary varus and valgus rotations resulting from ten newton-meters of varus and valgus torque in intact knees and after section.

Fig. 4-A: No isolated or combined section increased valgus rotation.

Fig. 4-B: Significant increases in varus rotation were found with combined section of the lateral collateral ligament (LCL) and deep structures and with combined section of the lateral collateral ligament, deep structures, and posterior cruciate ligament (PCL).

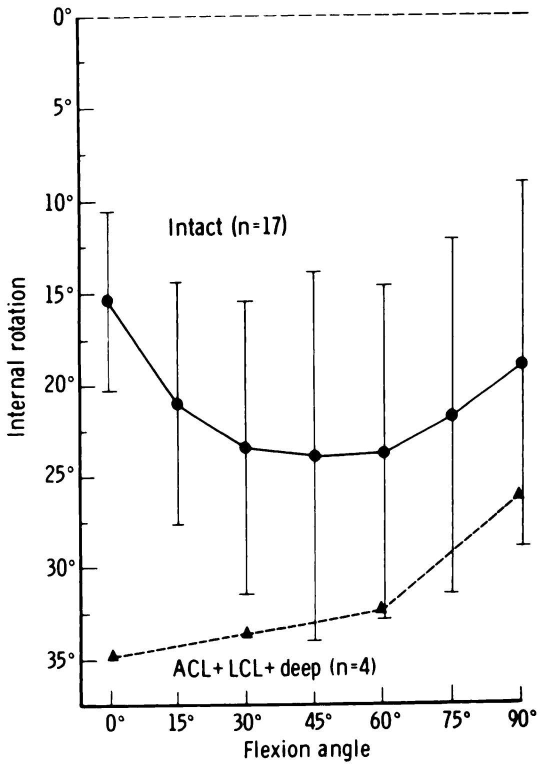

FIG. 5-A

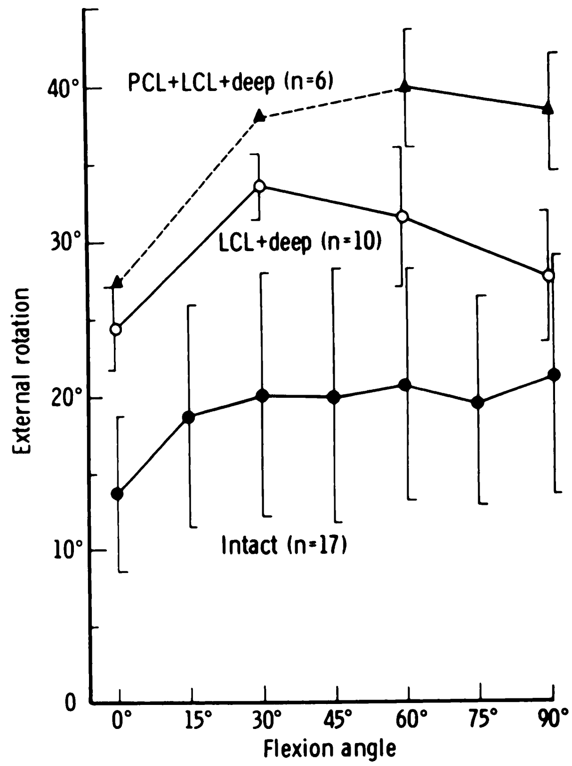

FIG. 5-B

Figs. 5-A and 5-B: Primary internal and external tibial rotations resulting from 4.5 newton-meters of internal and external tibial torque in intact knees and after section.

Fig. 5-A: Significantly increased internal rotation occurred only with combined section of the lateral collateral ligament (LCL), deep structures, and anterior cruciate ligament (ACL) at 30 and 60 degrees of flexion of the knee.

Fig. 5-B: Increased external rotation occurred at all angles of flexion with combined section of the lateral collateral ligament (LCL) and deep structures, with additional increases at 60 and 90 degrees when the posterior cruciate ligament (PCL) was then sectioned. The broken lines indicate a lack of statistical difference from the adjacent curve unless otherwise stated.

ligament was sectioned after combined section of the lateral collateral ligament and deep ligament complex.

Internal-External Rotation of the Tibia with Internal-External Tibial Torque

Total (internal plus external) tibial rotation in intact knees was least at zero degrees of flexion (approximately 29 degrees of rotation) and greatest at 45 degrees of flexion (approximately 44 degrees of rotation) (Figs. 5-A and 5-B).

No isolated or combined section of the lateral collateral ligament, deep structures, or posterior cruciate ligament produced an increase in internal rotation of the tibia. No significant increase in internal rotation of the tibia was found after isolated section of the anterior cruciate ligament. Large increases in internal rotation of the tibia (7 to 20 degrees) resulted when the anterior cruciate ligament, lateral collateral ligament, and deep ligament complex all were sectioned, but these increases were significant only at 30 and 60 degrees of flexion (Fig. 5-A).

Isolated section of the deep ligament complex produced a significant increase of 6 ± 3 degrees (four specimens) in external rotation at 90 degrees of flexion. Isolated section of the lateral collateral ligament produced significant but smaller increases of 2 to 3 degrees (seven specimens) at zero, 30, and 90 degrees of flexion. Section of both the lateral collateral ligament and the deep structures resulted in a significant increase in external rotation at all angles of flexion as compared with the intact knees (Fig. 5-B). Isolated section of the posterior cruciate ligament resulted in no change. When the posterior cruciate ligament was sectioned after the lateral collateral ligament and deep ligament complex had been cut, a significant increase in external rotation was produced at 60 and 90 degrees of flexion, but no increase occurred at zero or 30 degrees of flexion.

Anterior-Posterior Translation with Internal-External Tibial Torque

When internal tibial torque was applied to the intact knees, coupled anterior translation resulted, while the application of external tibial torque resulted in coupled posterior translation (Figs. 6-A and 6-B). The coupled total anterior and posterior translation that resulted from internal and external tibial torque was least (approximately two millimeters) at zero degrees of flexion and greatest (approximately four millimeters) at 90 degrees of flexion.

Isolated section of the lateral collateral ligament, the deep structures, or the posterior cruciate ligament did not alter the amount of anterior or posterior translation. However, when the lateral collateral ligament and the deep ligament complex were sectioned in combination, a significant increase in posterior translation occurred with external

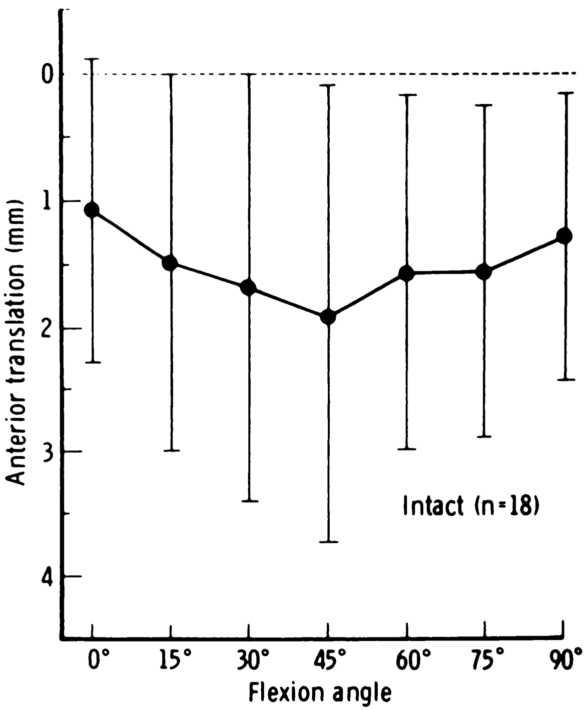

FIG. 6-A

Figs. 6-A and 6-B: Coupled anterior and posterior translations resulting from 4.5 newton-meters of internal and external tibial torque in intact knees and after section.

Fig. 6-A: No change in anterior translation was measured after section of any ligament.

torque at all angles of flexion (Fig. 6-B). Combined section of the lateral collateral ligament, deep structures, and posterior cruciate ligament produced an additional increase in posterior translation. This was not statistically significant using paired data (four specimens) but was significant at 60 and 90 degrees of flexion when mean translations were compared.

Finally, no isolated or combined section of the lateral collateral ligament, deep structures, or posterior cruciate ligament produced any change in the amount of anterior translation resulting from internal tibial torque. Section of the anterior cruciate ligament in combination with section of the lateral collateral ligament and deep ligament complex (four specimens) produced increases in anterior translation at 30 and 60 degrees of 7.4 ± 2.4 and 4.3 ± 2.9 millimeters, respectively.

Other Coupled Motions

In the intact knees, the application of a 4.5-newton-meter internal tibial torque resulted in coupled medial translations of 4.0 ± 2.8, 6.2 ± 3.3, 7.7 ± 4.4, 8.3 ± 4.6, 7.6 ± 5.0, 6.9 ± 4.0, and 5.9 ± 3.0 millimeters at zero, 15, 30, 45, 60, 75, and 90 degrees of flexion, respectively. The application of external tibial torque resulted in coupled lateral translations of 1.8 ± 0.7, 3.3 ± 2.0, 4.1 ± 3.2, 4.0 ± 2.7, 4.2 ± 3.6, 3.9 ± 3.5, and 4.4 ± 3.8 millimeters. Finally, as a result of the application of anterior or posterior force or internal, external, varus, or valgus torque, we could find no consistent or meaningful coupled translations or rotations, in either magnitude or direction, in intact knees or in knees that had an isolated or combined section of the ligaments.

Discussion

We have used the present method of testing in several studies of normal and abnormal motion of the knee[7,8,19,27]. The method uses loads and torques that approximate those that are applied during the clinical examination of the knee and records the resulting translations and rotations in intact knees and after selected soft-tissue section. Motion of the knee is always presented with reference to the neutral position of the intact knee. Our method offers one major advantage over methods that describe the restraining function of individual ligaments as a percentage of over-all restraint[3,9]; it directly measures the changes in motion of the knee that occur when each individual ligament is sectioned. In addition, the determination of the function of a ligament by measuring changes in motion of the knee within the 90-degree arc of flexion allows us to evaluate abnormalities of motion in a manner similar to that used in clinical testing and, thus, to determine at what angle of flexion the evaluation may be performed most accurately.

Although our method allows simulation of the clinical

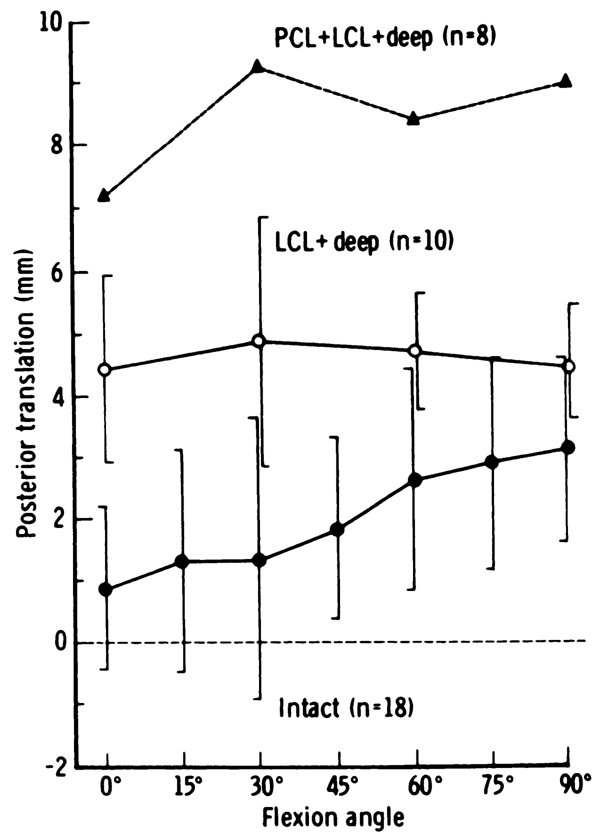

FIG. 6-B

Posterior translation increased after section of the lateral collateral ligament (LCL) and deep structures, and increased more at 60 and 90 degrees of flexion when the posterior cruciate ligament (PCL) was sectioned. The broken lines indicate a lack of statistical difference from the adjacent curve unless otherwise stated.

TABLE I

SEQUENCES OF SECTIONING OF THE LIGAMENTS

Sequence*	No. of Specimens
Intact ↦ deep	2
Intact ↦ deep ↦ lateral collateral ↦ anterior cruciate	1
Intact ↦ lateral collateral ↦ deep ↦ anterior cruciate	3
Intact ↦ deep ↦ lateral collateral ↦ posterior cruciate	3
Intact ↦ lateral collateral ↦ deep ↦ posterior cruciate	4
Intact ↦ posterior cruciate ↦ deep ↦ lateral collateral	2
Intact ↦ posterior cruciate ↦ lateral collateral ↦ deep	2
Total	17

* Deep = popliteus-arcuate complex.

examination, several sources of error need to be discussed. Our specimens were prepared without skin by cutting across the quadriceps and hamstring muscles and the iliotibial band. We do not believe that this method of preparation affected the results because of the passive nature of the test. We were also concerned about the effects of lysis of tissue and dehydration of deep tissue after removal of the skin. However, each specimen was thawed and tested within twenty-four hours, and intermittent moisturizing of the tissues was done.

Another source of error, independent of changes in the specimens, is that motion of the knee can be expected to depend on the order in which the ligaments are sectioned. To evaluate this possible error, several sequences of sectioning were employed (Table I). At the forces and torques that were chosen for testing, no significant alterations in translations or rotations were measured when different sequences were used. Analysis of the data revealed that the statistical variance in the measured translations and rotations that resulted from the use of different specimens was greater than any other factor in the test.

Lateral Collateral Ligament and Deep Structures

Our findings indicated that when a varus moment is applied to the knee, the lateral collateral ligament is the major restraint to primary varus rotation at all positions of flexion. No change occurred in primary internal rotation of the tibia or in coupled anterior and posterior translation after isolated section of the lateral collateral ligament. However, primary external rotation increased at all angles of flexion except 60 degrees. Section of the deep structures alone did not affect primary or coupled varus or valgus rotation or primary or coupled anterior or posterior translation.

Section of the deep structures produced a significant increase in primary external rotation of the tibia at 90 degrees of flexion. Based on the data for two knees, the popliteus tendon was the only significant component. This is the only major structure that is positioned in an oblique fashion, and thus it is well suited to prevent external rotation of the tibia. Its tibial attachment is quite broad and is oriented obliquely, so that tension along the tendon is probably transmitted directly to the tibia. The popliteus tendon appears to function as both a static and an active restraint to external rotation rather than merely as an active muscle for internal rotation of the tibia.

When the lateral collateral ligament and deep structures both were sectioned, significant primary varus and external rotation of the tibia occurred, as compared with the situation when the lateral collateral ligament or deep structures alone were sectioned (Figs. 4-B and 5-B). The clinical implication of our data on varus rotation is that the small increase in varus rotation that occurs when there is an isolated injury of the lateral collateral ligament or deep structures is difficult to detect clinically. Conversely, a combined injury to the lateral collateral ligament and deep structures is easier to appreciate, particularly when the knee is in 30 degrees of flexion, due to the increased rotation that is present. Both Hughston et al.[12] and Trickey noted that injury to the lateral side of the knee is generally associated with injury to either the posterior cruciate ligament[12] or the anterior cruciate ligament[28]. This has also been our finding; however, milder degrees of varus rotation will occur, even when the knee is extended, if an injury is confined to the lateral collateral ligament and deep ligament complex.

Posterior Cruciate Ligament

Our results indicate that the posterior cruciate ligament is the only isolated ligament that provides initial restraint to primary posterior translation at all angles of flexion. This finding is supported by the data from other studies[2,3,7,10,22]. Our data also confirmed the finding by Fukubayashi et al. that the secondary restraints to posterior translation are less effective when the knee is in 60 and 90 degrees of flexion. Kennedy et al. and DeLee et al. reported that the test for posterior translation (drawer) may be equivocal when the posterior cruciate ligament is completely torn and the capsular structures are intact. In contrast, we found that isolated section of the posterior cruciate ligament produced increased posterior translation of the tibia at all degrees of flexion of the knee, with the greatest increases occurring between 75 and 90 degrees. Although pain, swelling, and muscular spasm may make it difficult to note, increased translation will generally be discernible in patients who have an injury that is restricted to the posterior cruciate ligament if the knee is tested at 75 to 90 degrees of flexion. In addition, absence of the posterior cruciate ligament has no effect on primary varus or external rotation of the tibia as long as the lateral collateral ligament and deep structures are intact.

Lateral Collateral Ligament, Deep Structures, and Posterior Cruciate Ligament

Combined section of the lateral collateral ligament, deep structures, and posterior cruciate ligament produced significant increases in primary posterior translation (Fig. 2-B), varus rotation (Fig. 4-B), and external rotation of the tibia (Fig. 5-B) at all angles of flexion of the knee when compared either with the intact knee or with a knee that had an isolated or lesser combination of ligament section.

These results suggest that the clinical equivalent of these three tests can be used to distinguish between an injury to the posterolateral ligamentous structures or the posterior cruciate ligament, or both. As compared with the situation in intact knees, isolated section of the posterolateral structures produced a significant (maximum) increase in primary posterior translation at zero and 30 degrees of flexion of the knee (Fig. 2-B) and a significant increase in primary external rotation at all angles of flexion (Fig. 5-B). In comparison, isolated section of the posterior cruciate ligament resulted in a large (maximum) increase in posterior translation at 75 and 90 degrees of flexion of the knee, as compared both with intact knees and with knees in which the posterolateral ligaments had been sectioned, and a minimum increase at zero and 30 degrees as compared with intact knees. No increase occurred in posterior translation at zero and 30 degrees of flexion of the knee when compared with the knees in which only the posterolateral structures had been sectioned, nor was there any change in primary external rotation of the tibia compared with the results in intact knees. Thus, to distinguish between an isolated rupture of the posterolateral structures or the posterior cruciate ligament, a knee in which the former injury is suspected should be tested at zero to 30 degrees of flexion for maximum primary posterior translation and at 75 to 90 degrees for external rotation and minimum translation. The knee in which isolated injury of the posterior cruciate ligament is suspected should be tested at 75 to 90 degrees of flexion for maximum primary posterior translation and at zero to 30 degrees for minimum translation; no change should be expected in primary external rotation. A posterolateral injury will result in significant increased coupled external rotation of the tibia resulting from a posterior force, while isolated rupture of the posterior cruciate ligament will result in complete loss of the coupled external rotation that is characteristic of an intact posterior cruciate ligament. Finally, if both the posterolateral structures and the posterior cruciate ligament are ruptured, there will be a substantial increase in primary posterior translation, external rotation, and varus rotation at all angles of flexion of the knee compared with an intact knee or a knee in which either structure has been injured in isolation.

Our findings do not support those of Hughston et al.[12] regarding the absence of all so-called rotatory instabilities of the knee once the posterior cruciate ligament has been ruptured. We found that the posterior cruciate ligament provided substantial restraint to primary varus rotation (Fig. 4-B) and primary external rotation of the tibia (Fig. 5-B) after section of the posterolateral structures. Jakob et al. emphasized this in their studies but did not quantify the findings. Isolated section of the posterior cruciate ligament resulted in no significant change in any of the measured rotations except for a loss in the coupled external rotation of the tibia. However, when the posterior cruciate ligament was sectioned in combination with the posterolateral structures, there were substantial increases in coupled external rotation of the tibia (Fig. 3-B), primary varus rotation (Fig. 4-B), primary external rotation of the tibia (Fig. 5-B), and coupled posterior translation (Fig. 6-B). These rotatory motions can be directly related to the location of the axis of rotation between the femur and the tibia and the moments that are generated about this axis by each of the ligamentous structures of the knee. In an intact knee, these structures will cause the tibia to translate and rotate to a position of equilibrium (a balanced position) to resist the specific applied forces or moments (torques). When one of these structures is sectioned, the balancing forces that are exerted by each (that is, their moments about the axis of rotation) will change as the knee moves to a new position of equilibrium to compensate for absence of the ligament. For instance, when the posterior cruciate ligament is sectioned, coupled external rotation of the tibia is lost, indicating that the direction of the force that is generated by the posterior cruciate ligament must pass on the medial side of the axis of rotation in the intact knee in order to produce external rotation[7]. Since section of the posterolateral ligaments alone or in combination with the posterior cruciate ligament resulted in substantial rotatory motions, the deep structures appear to be capable of exerting a significant rotatory moment about the axis of rotation. As the axis shifts with motion of the knee, these rotatory moments will change and possibly will shift the restraining proportions of these two structures. It is for this reason that it is essential to perform tests on cadavera using a system of multiple degrees of freedom to avoid abnormally constraining motion of the knee[3,9].

Lateral Collateral Ligament, Deep Structures, and Anterior Cruciate Ligament

Our data support those of Hsieh and Walker, indicating that increased primary internal rotation of the tibia will not occur after section of the anterior cruciate ligament (Figs. 5-A and 5-B). This is in contrast to our previous clinical impression that increased internal rotation occurs during the pivot-shift maneuver. Possibly we are either misinterpreting anterior and posterior translation as internal rotation or there may be injury to additional structures, such as the lateral collateral ligament and popliteus tendon. Our data demonstrate that although primary internal rotation is not increased after section of the anterior cruciate ligament, it is increased significantly when the lateral collateral ligament and popliteus tendon have been sectioned in addition (Fig. 5-A). It is apparent that the clinician must carefully assess the posterolateral corner of the knee in evaluating patients who have a tear of the anterior cruciate ligament, as this pattern of combined injury occurs often[5].

Previously we had assumed that isolated injury to the anterior or posterior cruciate ligament would result in external and internal rotation. The results of our study indicate that the lateral collateral ligament or deep structures (popliteus-arcuate complex) are the major restraints that prevent primary external rotation.

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