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Three-dimensional motion analysis of clinical stress tests for anterior knee subluxations

Frank R. Noyes[1, 2], Edward S. Grood[1, 2] and Wilfredo J. Suntay[2]

The three rotations and three translations that comprise total knee motion were simultaneously measured in cadaveric knees during the commonly employed clinical tests for anterior cruciate injury. A second study determined the three-dimensional motions that occurred when known forces and moments were applied. A total of eight whole lower limbs were studied. A 6 degree-of-freedom instrumented linkage (3-D electrogoniometer), rigidly mounted to the tibia and femur, was used. The ligaments sectioned included the lateral extraarticular restraints (iliotibial band, lateral capsule) and the anterior cruciate ligament, both separately and in combination.

After sectioning the anterior cruciate ligament alone, anterior displacement of both the medial and lateral tibial condyles increased markedly during the flexion rotation drawer and pivot shift tests. At 30° knee flexion, total anterior-posterior displacement increased 100 percent, but internal-external tibial rotation increased only 15 percent.

In all the anterior displacement type of clinical tests (including Lachman's test), there was not a true rigid coupling of knee motions because the examiner controlled the amount of internal tibial rotation and anterior tibial translation. After anterior cruciate sectioning alone, both the lateral and medial tibial condyles displaced anteriorly. Sectioning the medial structures caused additional anterior translation of the medial and lateral tibial condyles.

We measured many different combinations of motions that depend on the ligament and capsular structures injured, the clinical test used, and how the clinician performed the test. Differing types of anterior subluxation require that the separate subluxations of the medial and lateral tibial condyles be determined during each stress test.

Disagreement exists as to the abnormalities in anterior tibial translation and internal tibial rotation that occur after anterior cruciate ligament injuries, alone and in combination with injuries to the medial and lateral ligamentous structures.

The first objective of this study was to determine the 3-dimensional motions that occur during the commonly employed stress tests for anterior subluxations of the knee joint. In this context, we wished to determine how anterior tibial translations are coupled with internal-external tibial rotations during the clinical tests.

Our second objective was to develop a more detailed classification of different types of anterior subluxation. We have addressed the necessity of classifying anterior subluxations of the knee elsewhere (Noyes and Grood 1987, Noyes 1988, Grood and Noyes 1988). This paper presents some of the specific data on which these recommendations are based.

Noyes-Giannestras Biomechanics Laboratory[2], University of Cincinnati, College of Engineering, Cincinnati, OH, 45221, U.S.A., and Cincinnati Sportsmedicine and Orthopedic Center[1], The Deaconess Hospital, Cincinnati, OH 45219, U.S.A.

Correspondence: Frank R. Noyes, M.D., The Cincinnati Sportsmedicine and Orthopedic Center, The Deaconess Hospital, 311 Straight Street, Cincinnati, OH 45219, U.S.A.

Materials and methods

Cadaveric specimens

For this study, we used eight whole lower limbs from 5 cadavers. The average age at the time of death was 47 (30–68) years. All the specimens were stored unembalmed at –15 °C. The night before testing, the specimens were thawed and then tested at room temperature. An examination of knee joints prior to the testing excluded traumatic changes and arthritis or ligamentous injury that would affect the results.

Analysis of three-dimensional knee motions

The 3-dimensional position and motion of the knee joint were measured using a 6 degree-of-freedom electrogoniometer (Grood et al. 1979, Grood et al. 1981, Grood and Suntay 1983, Suntay et al. 1983). The position of the tibia with respect to the femur was expressed in terms of six clinical parameters: the three angles of flexion-extension, abduction-adduction, and internal-external tibial rotation; and the position of selected points along three axes oriented in the anterior-posterior, medial-lateral, and proximal-distal direction of the knee (Grood and Suntay 1983). The anterior-posterior positions of the following three points on the tibia were measured: 1) a point located in the center of the tibia midway between the spines and 2) the positions of two points, one located at each margin (medial and lateral edges) of the tibial condyles. The points at the condyle margins were located along a line, oriented in the medial-lateral direction of the tibia, that passed through the point located between the spines. This approach was used in order to separately measure the positions of each condyle. The motions were displayed to the examiner during the manual examination and stored on a magnetic disk for later analysis.

Manual laxity examination

All the manual tests were conducted by 1 examiner (FRN) using a methodology as close as possible to the original (Cabaud and Slocum 1977, Galway and MacIntosh 1980, Gerber and Matter 1983, Grood et al. 1981, Losee et al. 1978, MacIntosh and Galway 1972, Norwood et al. 1979, Noyes et al. 1980b, Noyes et al. 1983, Slocum et al. 1976, Torg et al. 1976). Before conducting the tests the lower limb preparation was positioned on an examination table to simulate clinical conditions (Grood et al. 1981). Seven stress tests were performed:

1) anterior displacement test at 15° knee flexion (Lachman test) with an anterior pull alone and in combination with either an internal or external tibial rotation to accentuate the subluxation of the lateral or medial tibial condyles (Losee et al. 1978);

2) anterior displacement test at 90° knee flexion (drawer test) with an anterior pull alone or in combination with internal or external tibial rotation;

3) anterior displacement test at 90° knee flexion with the tibia either externally or internally rotated before testing;

4) flexion rotation drawer test (Noyes et al. 1980a);

5) pivot shift test (Fetto and Marshall 1979, Galway and MacIntosh 1980, Hughston et al. 1976, MacIntosh and Galway 1972);

6) anterolateral rotatory instability test (Slocum et al. 1976);

7) leg elevation (leg pick-up) test, in which the anterior tibial subluxation occurs in simply lifting the leg.

Each test was repeated 4–5 times, and the motions of the tibia were measured and analyzed.

Limits of motions

The limits (extremes) of motion of the knee (Noyes et al. 1989) were measured under known loads applied to the intact knee and after sectioning various ligamentous structures. The femur was rigidly attached to a platform, allowing the knee to be flexed and extended by femoral rotation while the tibia hung freely by its own weight. We used a traction apparatus to apply A/P forces and internal-external torques to the knee. The electrogoniometer was used to determine the equilibrium position as the femur was flexed and extended.

We conducted four types of limit tests. In the first test, an internal tibial rotation torque of 5 newton meters was applied through a torque ring. In a second, similar limit test, an external tibial rotation torque was applied. The third limit test measured the amount of anterior displacement when a 67 newton anterior force was applied and the tibia manually rotated internally and externally. The force was applied using a traction apparatus connected to a strap laced around the calf just below the joint line. This test was conducted at 15°, 30°, 60°, and 90° knee flexion. In the fourth limit test, similar to the third, a posterior force of 67 newtons was applied.

Ligament sectioning procedure

We first measured the 3-dimensional motions during the manual and limit tests on intact normal knees. Two ligament cutting sequences were used on three right-left pairs of cadaveric limbs. In one cutting sequence, the anterior cruciate ligament was transected and the clinical stress and limit tests repeated. The iliotibial tract and anterior and middle thirds of the lateral capsule were then transected and the tests repeated. The attachment of the iliotibial tract from the lateral intermuscular septum to its tibial attachment was removed to eliminate the entire restraining function of this structure. The lateral capsule was sectioned just in front of the lateral collateral ligament, cutting the middle and anterior one-thirds of the lateral capsules. The posterolateral capsule and arcuate complex were left intact.

The other ligament cutting procedure involved the reverse order: sectioning the iliotibial tract and lateral capsule first, repeating the stress and limit tests, then cutting the anterior cruciate ligament.

Results

Increases in anterior tibial translation occurred after sectioning the anterior cruciate ligament for all the stress tests except the anterior drawer test conducted at 90° knee flexion (Table 1). After sectioning the iliotibial band and lateral capsule, further anterior translation occurred for the anterior drawer tests, but not for the pivot-shift type of tests. Increases in internal tibial rotation after sectioning the anterior cruciate ligament were generally negligible except for the pivot shift test which produced nearly a twofold increase. Similarly, there were no increases in internal tibial rotation after sectioning the iliotibial band and lateral capsule as long as the anterior cruciate ligament was intact. Sectioning of both the anterior cruciate ligament (primary restraint) and the iliotibial band and lateral capsule (secondary restraints) resulted in increased internal tibial rotation. However, the increase again was minimal except for the pivot shift test.

Because the clinical stress tests were performed without simultaneous measurement of the forces applied, the data are presented in a qualitative manner only, thus providing the general pattern of motions that occur during each test.

Anterior drawer test at 15° (Lachman test)

An anterior pull means that an anterior displacement of the tibia was induced in which tibial rotation was neither enhanced nor constrained.

A small amount of internal rotation did occur during the test as the tibia was pulled anteriorly. When a manually imposed internal tibial rotation was combined with the anterior displacement, there was no change in total anterior-posterior translation. Ligament sectioning produced increased anterior translation with a negligible change in internal rotation (Figure 1).

Anterior drawer test at 90°

When the tibia was pulled anteriorly, both anterior translation and internal tibial rotation occurred. The amount of internal rotation was reduced by purposely applying external rotation during the test and increased by applying internal rotation.

When the test was performed with the tibia placed in an externally rotated position prior to the examination, the added external tibial rotation limited the amount of anterior translation that occurred. The tibia still tended to rotate internally as it translated anteriorly. Because this tendency was further increased or decreased by the

Table 1. Tibial translation and rotation before and after ligament section. Mean *SD*

		Anterior drawer 15° flexion						
	n	Anterior pull	Anterior pull + int. rotation	Anterior drawer 90° flexion	Flexion rotation drawer	Pivot shift	ALRI (Slocum test)	Leg pick-up
AP tibial translation (mm)								
Intact knee	6	9.1 *2.5*	10 *3.1*	8 *3.2*	7.5 *2.1*	6.6 *1.7*	3.8 *3.7*	5.6 *1.1*
ACL cut	3	17 *3.1**	18 *3.6**	12 *4*	15 *3.5**	16 *3.9**	9.1 *0.1**	13 *2.1*
Iliotibial tract/lateral capsule cut	3	10 *2.7*	11 *3.4*	8.2 *3.7*	7.6 *2.3*	5.6 *1.4*	4.7 *5.4*	5.8 *2.9*
Anterior cruciate ligament + iliotibial tract/lateral capsule cut	6	20 *3.6**	21 *4.7**	16 *4.0**	16 *3.4**	15 *4.3**	11 *3.3*	13 *2.4**
I/E tibial rotation (°)								
Intact knee	6	1.4 *1.4*	17 *5.2*	3.5 *1.7*	14 *3.3*	13 *2.4*	6.6 *2.4*	5.6 *1.5*
ACL cut	3	6.4 *1.2**	14 *2.3*	3.8 *1.5*	17 *2.9*	22 *4.9**	8.8 *4.9*	8.3 *2.9*
Iliotibial tract/lateral capsule cut	3	2.6 *3*	14 *5.6*	5.2 *1.1*	13 *4.5*	12 *2.7*	8.4 *4.2*	5.8 *1.9*
Anterior cruciate ligament + iliotibial tract/lateral capsule cut	6	7.8 *2.3**	18 *6.2*	6.6 *1.7*	17 *4.4**	21 *7.4**	15 *4.1**	7.8 *3.5*

**p* < 0.05 compared with the intact knee by the Duncan multiple range test.

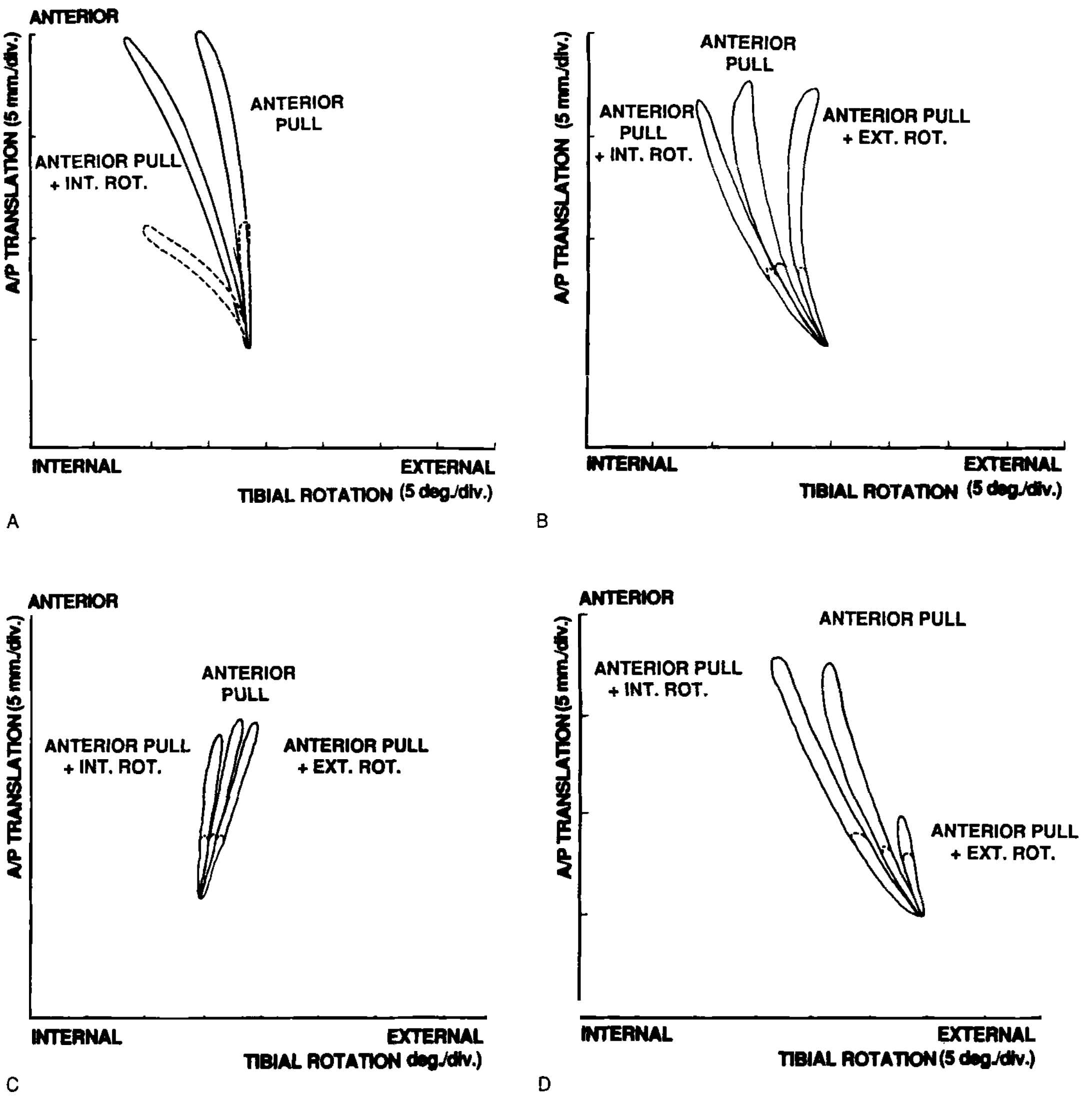

Figure 1. Anterior translation versus tibial rotation is shown during the various anterior drawer-type tests. The motion is shown for the intact knee (dashed line) and after ligament sectioning of the anterior cruciate ligament, the iliotibial tract, and the lateral capsule (solid line). A. At 15°(Lachman). B. At 90°, starting with the tibia in the neutral position, C, externally rotated 10°, and D, internally rotated 15° (Figures 1A and 1B are modified and reproduced with permission from Noyes and Grood 1987).

way the examiner conducted the test, it did not represent a rigid coupling of obligatory motions.

When the anterior (drawer) test was performed with the tibia first placed in an internally rotated position, the amount of anterior translation decreased markedly. The tibia's tendency to internally rotate with anterior displacement was no longer evident (Figure 1).

Figure 2 shows, for 1 specimen, how the limits of A/P translation at 90° flexion depend on the tibial rotation position for the intact knee and after cutting the anterior cruciate ligament. Superimposed on the A/P limits are drawer tests performed with the knee initially in internal, neutral, and external rotation. The greatest amount of A/P translation was obtained in the region of neutral tibial rotation. A/P translation decreased markedly when the tibia was maximally rotated at the start of the (drawer) test, with internal rotations reducing the translation more than external rotations. The results show that the examiner controls the amount of A/P translation, first by selecting the initial rotational position of the tibia, and secondly, by rotating the tibia during the test.

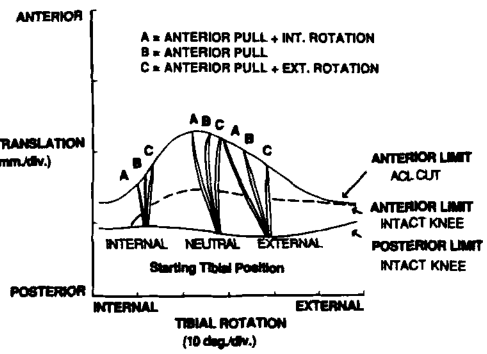

Figure 2. Anterior drawer, 90° flexion. The amount of antero-posterior translation depends on the rotation position of the tibia at the beginning of the test (Modified and reproduced with the permission of Noyes and Grood 1987).

Flexion rotation drawer test

The changes in A/P translation and tibial rotation that occurred during the flexion rotation drawer (FRD) test are shown in Figure 3. The test involved lifting the tibia up (anterior displacement) during knee extension and pushing the tibia down (posterior displacement) during knee flexion. The rotational component of the motion was due to rotation of the femur. The tibia was initially held in a neutral to slightly external rotation position so as not to constrain the motions of the knee joint. All the specimens tested demonstrated patterns of motion similar to those shown in Figure 3.

The test started at "A," the most extended position, with the lower extremity simply supported against gravity. The weight of the femur caused it to drop posteriorly and externally rotate, producing the starting position with the tibia anterior and internally rotated. During the test, the tibia was lifted anteriorly; as the knee was flexed, the tibia was pushed posteriorly, reaching point "C," the most flexed position. In addition to the posterior displacement, internal-external rotation also occurred. After sectioning the ACL (solid curve), the tibia was displaced anteriorly and rotated internally as the femur dropped posteriorly under its own weight and externally rotated, producing a subluxated position of the knee joint. The subluxation was increased slightly as the tibia was lifted (flipped) upward (position B) at the start of the test. At approximately 30° knee flexion, the leg was pushed posteriorly reducing the tibia into a normal relationship with the femur (position C). From position C to position A, the knee was extended and returned to the subluxated position.

Table 1 shows the average peak-to-peak values for A/P translation and tibial rotation during the FRD test. The mean values and standard deviations are given to show the differences between tests obtained by 1 examiner. The data are not meant to give quantitative displacement changes, because the forces applied by the examiner were not measured. A twofold increase in anterior translation occurred after anterior cruciate sectioning ($p < 0.05$); however, there was no certain

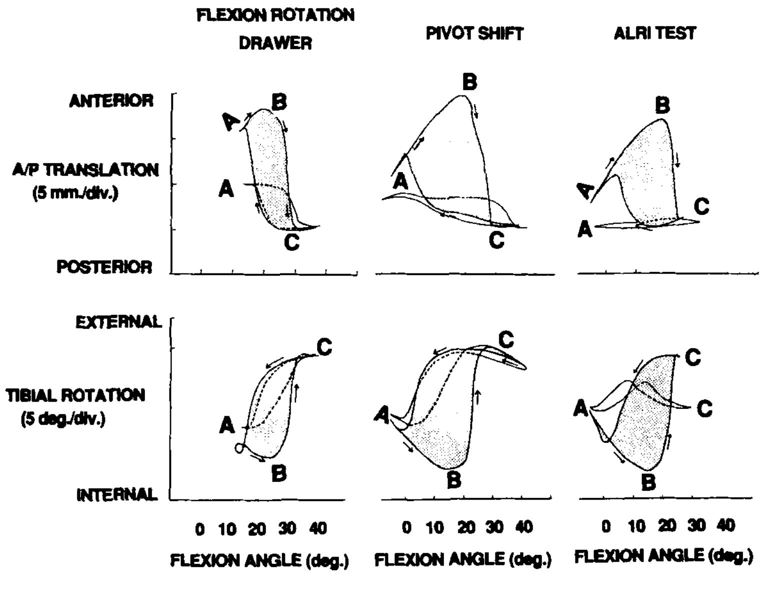

Figure 3. Anterior translation motion (A) and tibial rotation (B) versus knee flexion. The motion is shown for the intact knee (dashed line) and after sectioning (solid line). All the curves are from one knee for comparison. The anterior cruciate ligament, iliotibial band, and lateral capsule were sectioned. Position A equals the starting position of the test, B is the maximum subluxated position, and C indicates the reduced position (Modified and reproduced with permission from Noyes and Grood 1987).

increase in tibial rotation. After additional sectioning of the lateral extraarticular tissues, a small increase in internal tibial rotation was recorded. Sectioning only the extraarticular lateral restraints, with an intact anterior cruciate ligament, produced no increase in tibial translation or rotation.

Pivot shift test

The sequence of knee motions during the pivot shift tests are shown in Figure 3. After removing the anterior cruciate ligament, the maximum subluxated position was reached (position B) by the marked internal rotation torque on the tibia while also producing a valgus loading to the joint. With flexion, a sudden reduction phenomenon occurred between positions B and C. It was this motion that produced the characteristic thud sensation. With knee extension, anterior tibial translation increased at about 10° knee flexion. A true reduced position was only obtained at position C and not at position A, where the tibia was anteriorly subluxated. The amount of tibial rotation in the pivot shift tests was larger than in the other tests (Table 1).

The jerk test (Hughston et al. 1976) represents the reverse of the pivot shift tests in going from the reduced position in flexion (position C) to the subluxated position (position B) in extension.

Anterolateral rotatory instability (Slocum) test

(Slocum and Larson 1968)

In Figure 3, the Slocum test started at position A, where an anterior displacement and internal rotation torque were applied to the tibia to increase the subluxation, reached a maximum at position B, and was followed by a reduction at position C. With knee extension the cycle was completed. The amount of rotation and translation that occurred was less for this test than the other tests (Table 1).

Anterior tibial drawer during leg pick-up

In simply lifting the leg, a significant amount of anterior tibial translation occurred after the combined ligament cutting procedure (Table 1). This effect was noted when the limb was placed into any position in which the weight of the thigh caused the femur to drop posteriorly (gravity-induced anterior tibial translation). Knee flexion reduced the gravity effect and the anterior translation was eventually eliminated. There was less tibial rotation during this maneuver than during the other tests.

Abduction-adduction test

The increased anterior translation after anterior cruciate sectioning affected the abduction-adduction clinical stress tests. An anterior tibial subluxation occurred due to the femur falling posteriorly under its own weight when the leg was held elevated above the examining table (Figure 4, top curve). When the thigh was resting on the table (bottom curve), gravity reduced the anterior tibial subluxation. In the elevated position, anterior translation increased with abduction. With the limb over the side of the table, the opposite occurred and the tibia moved posteriorly with abduction. In the reduced position with the leg over the side of the table, the examiner found it easier to control the knee and thereby produce maximal abduction-adduction motions.

Medial and lateral tibiofemoral compartment translation

The amount of tibial translation was measured separately for the lateral and medial tibiofemoral compartments (Figure 5) during the flexion rotation drawer test, first in the intact knee and then after sectioning the anterior cruciate ligament, lateral capsule, and superficial medial collateral ligament. After sectioning the ACL, the increase in translation for the lateral compartment was greater than for the medial compartment, indicating a rotational motion. The slight increase in translation after sectioning the lateral capsule (including the iliotibial tract) indicates that this structure was not tight (i.e., physiological looseness). Sectioning the superficial tibial collateral ligament (long fibers) further increased both medial and lateral compartment translation.

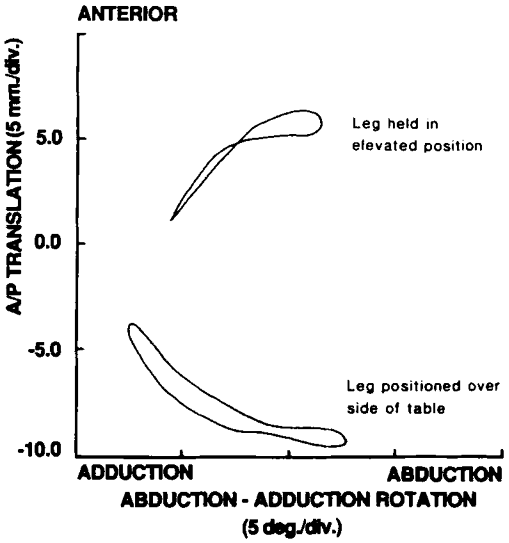

Figure 4. Anterior tibial translation during the abduction-adduction test. The test was performed with the leg over the side of the table (gravity-reduced position) and with the leg supported (gravity-subluxated position). Placing the leg over the side of the table allowed the test to be conducted in the reduced position.

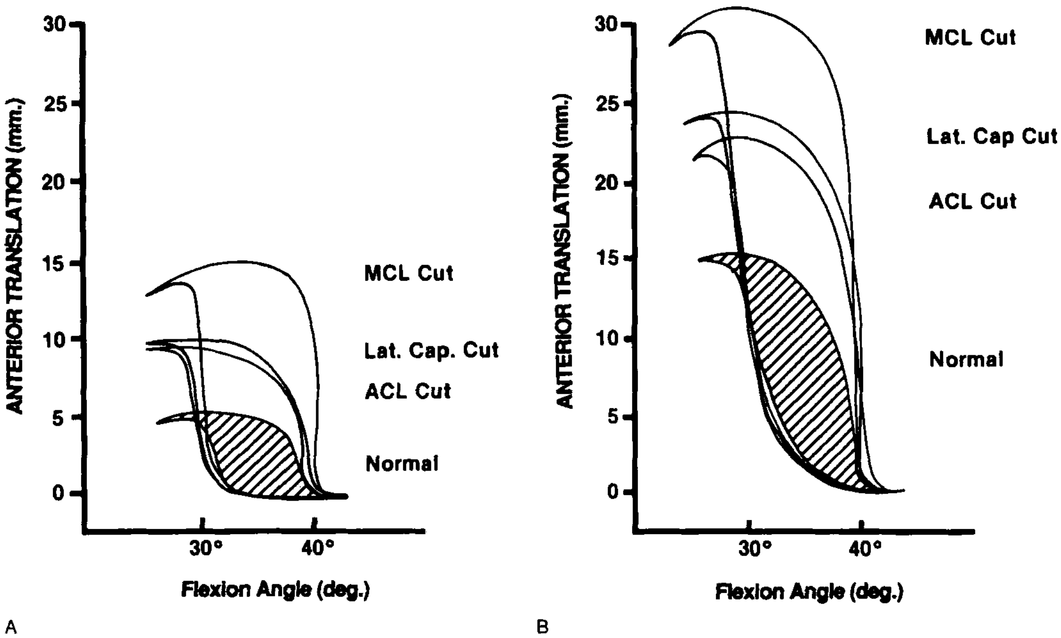

Figure 5. The amount of anterior tibial translation is shown separately for the medial (A) and lateral (B) tibiofemoral compartments during the flexion rotation drawer test (Reprinted with permission from Noyes and Grood 1987).

Discussion

The usual description of "anterolateral rotatory instability" depicts the lateral tibial condyle moving anteriorly (subluxated) with respect to the lateral femoral condyle while the medial tibiofemoral compartment remains in a relatively normal position. The motion is described as an increase in internal tibial rotation with the vertical axis of tibial rotation within the medial tibiofemoral compartment. Our data indicates this description is incorrect. First, the axis of tibial rotation has not, to our knowledge, been previously measured after anterior cruciate sectioning; therefore, its anatomic location, as described in published reports on the classification of rotatory subluxations, represents a guess. Our results showed that during the Lachman and pivot shift-type tests there was a significant increase in anterior translation of both tibial condyles and that the axis of tibial rotation was located outside of the knee joint. In all the stress tests, the increase in tibial translation was greater than the increase in tibial rotation. In the limit tests, conducted under known forces, A/P translation increased approximately 100 percent while internal/external rotation increased only 15 percent.

Coupled motions

Torzilli et al. (1981) have shown that an internal tibial rotation coupled with anterior tibial translation occurs when an anterior force is applied to an intact cadaver knee. The coupled motions disappeared when the anterior cruciate ligament was removed. In our study, we found that a coupled internal rotation occurred both in the intact knee and after the ligament was removed. Further, the coupling was not obligatory, but controlled by the examiner. Prior studies used isolated knee specimens with most of the bone and muscle removed and the tibia mounted horizontally with the femur flexed (Markolf et al. 1976, Markolf et al. 1978, Wang et al. 1975). In this study, whole lower limbs were employed with an artificial ball-in-socket joint replacing the normal hip. The position of the leg was typical of its position during the clinical examination, thus duplicating any effects gravity might have. Further, the forces were applied manually, whereas prior cadaver studies were performed using a specially designed experimental apparatus. The coupled rotations in this study resulted from the way the clinical examination was performed and only indirectly reflected any inherent coupling of knee motions.

Three-dimensional motion analysis

Several prior studies described normal and pathologic motions of the knee using instant center analysis (Gerber and Matter 1983, Tamea and Henning 1981). This approach, popularized by Frankel et al. (1971), uses the method of Reuleaux to determine the "instant center" of knee flexion. The point determined using the Realeaux method is not the true instant center and is more correctly called a pole (Harrisberger 1961). The pole has the following properties: if the joint is at position A, a rotation around the pole would bring the joint exactly to position B. This circular motion around the pole is not the actual motion the joint took in going from position A to position B. In fact, the two motions can be quite different. The common use of the pole to approximate the instant center is based on the assumption that the motion is smooth (not jerky or erratic), implying a near circular motion between positions A and B. In this case the pole approximates the position of the instant center at a joint position halfway between A and B. If the motion is jerky or erratic, such as may occur during the pivot shift test, then the pole is probably not a good approximation of the actual motion and instant center. A further experimental complication also exists in determining the location of the rotation axis. Panjabi (1979) has shown that the accuracy of determining the location of the rotational pole with the Reuleaux method deteriorates if the amount of rotation used in an experiment is less than 10°.

The problem of instant center analysis and the complexity of knee motions require that knee instabilities be analyzed in a different manner than previously used. It is important to distinguish three concepts related to joint motions. The first is joint position, which describes where the bones are located with respect to each other (i.e., subluxated or normal relationship of both tibial condyles). The second concept is motion (change in position), which is described by the sequential positions that occur. The third concept is the increased range of motion or change in the limits of motion that produces the joint subluxation. Each degree-of-freedom or independent motion component has two limits, one for each sense, forward and backward. This produces 12 motion limits in the knee joint.

Tibial translations are described by the displacement of a reference point on the tibia. Because the amount of translation depends upon the point's location on the tibia, this location must always be stated (Grood et al. 1981, Grood et al. 1979, Grood and Suntay 1983). Medial-lateral translation of the tibia is the component (vector dot product) of the displacement of the reference point along the flexion axis. Anterior-posterior translation of the tibia is the component along the abduction-adduction axis, and tibial axial translation is the component along the tibial internal-external rotation axis. The importance of measuring the full 6 degrees-of-freedom was demonstrated by this study, because during the clinical tests the motions were found to be strongly nonplanar. Specifically, significant tibial rotation occurred as the knee was flexed, and the direction of the instant axis of rotation continually changed.

Diagnosis of knee ligament injuries

Over the past several years, it has become commonly accepted to classify ligament injuries based on the abnormal motions that occur during the clinical tests. We disagree with this approach for several reasons. First, there are different patterns of motion based on: 1) the clinical test performed, 2) the primary and secondary ligamentous restraints that are injured, and 3) the manual forces applied during the examination. Thus, it is impossible for any classification system based on joint motion to represent a specific clinical entity in terms of the ligamentous lesion that exists. A classification system based on abnormal motions must necessarily provide rather long lists of the differing types of ligamentous injuries that may or may not occur.

We believe the classification and diagnosis of injury should be based on the anatomic deficit present and the ligaments that are injured. The physician selects appropriate clinical tests to evaluate the various primary and secondary ligamentous restraints (Butler et al. 1980, Fetto and Marshall 1979, Grood et al. 1979, Lipke et al. 1981, Marshall et al. 1978, Noyes et al. 1980b, Noyes et al. 1980c, Noyes et al. 1983a, Noyes et al. 1983b). The best stress tests permit analysis of the primary restraints where secondary restraints are most slack, thereby reducing the risk of a false negative test (Noyes et al. 1980c). This is not to say that an anatomic classification system of injury is not without its problems. It is often difficult to clinically determine which ligaments are injured and the degree of injury (Noyes et al. 1980c).

We propose the use of a more rigorous analysis of abnormal knee motions in clinical stress tests that addresses the following:

1) In which one of the 6 degrees-of-freedom is the motion increased? The motions analyzed in the clinical examination are in all three rotational degrees of freedom, namely, flexion-extension (hyperextension), internal-external tibial rotation, and abduction-adduction rotation, and one translation, anteroposterior. There is less emphasis on medial-lateral and compression-distraction translation; however, they may also be increased. The clinician must select appropriate tests that either control, constrain, or take into account the motion in each degree-of-freedom. Combined motions, such as A/P translation and tibial rotation, occur in many stress tests (i.e., the pivot shift type of test), and this must be understood from a qualitative standpoint.

2) In the clinical test, the other degrees-of-freedom must be specified. Different amounts of motion will be

obtained depending on the joint position before the test. For example, the total anterior-posterior translation depends on knee flexion and tibial rotation.

3) What subluxations of the joint occur during the clinical test? More than one type of subluxation is usually possible. We have provided elsewhere the different anterior subluxations that are possible. An injury to one or two primary ligamentous restraints commonly allows several different subluxations. In the rotatory subluxations, the A/P displacement of the lateral and medial tibial condyles must be described separately. There are only three positions possible: anterior subluxation, normal relationship, or posterior subluxation of each tibial condyle.

Anterior displacement (drawer) tests

We routinely palpate the medial and lateral tibial condyles and estimate the amount of individual compartment displacement and subluxation. If the medial compartment displaces anteriorly, similar to the lateral compartment, this indicates involvement of the medial extraarticular restrains in addition to lateral extraarticular restraints. We first perform an anterior tibial displacement, neither enhancing nor constraining associated tibial rotation. We then repeat the test, performing an anterior displacement plus internal tibial rotation to test for the maximum amount of subluxation to the lateral tibiofemoral compartment, and anterior displacement plus external tibial rotation to test the maximum amount of subluxation to the medial tibiofemoral compartment.

For the traditional anterior displacement (drawer) test conducted at 90° knee flexion, our results show that rotation of the tibia externally or internally at the start of the test may limit the amount of tibial translation. Because it is difficult to quantitate how much tibial rotation is applied, there is difficulty in making comparisons between knees. Also, it is important not to internally or externally rotate the tibia into a maximum position at the start of the test, for this may decrease the anterior displacement due to tightening of the extraarticular structures. For example, rotating the tibia internally tightens the iliotibial band, blocking anterior displacement and producing a false negative test in knees with anterior cruciate tears.

Table 2. Classification of pivot shift and flexion rotation drawer tests

Qualitative grading	Structures involved: Anterior cruciate ligament	Iliotibial band lateral capsule	Medial ligaments, capsule	Positive tests	Comments
Normal	–	–	–		Physiological laxity normally present.
Moderate (Grade I)	+	–	–	Lachman test, flexion-rotation drawer Losee Test, ALRI, pivot shift "slip" but not "jerk"	Subtle subluxation-reduction phenomena. Secondary ligament restraints limit the amount of joint subluxation. Pivot shift and jerk tests do not show obvious jump, thud, or jerk, although, with experience, the subluxation may be detected as a "slip".
Severe (Grade II)	+	+	–	All tests positive	Hallmark is an obvious jump, thud, or jerk with gross subluxation-reduction during the test. There is a normal physiological looseness of the lateral secondary ligamentous restraints at 20° flexion. This allows a greater subluxation ot the lateral tibial condyle.
Gross (Grade III)	+	++	++	All tests positive	Hallmark is a gross subluxation with impingement of the posterior aspect of the lateral tibial condyle against the femoral condyle. The examiner must effect reduction to allow further knee flexion. There is also a gross anterior subluxation of the medial tibial condyle.

+ ligamentous structure is loose; – ligamentous structure is not loose
Modified from Noyes, F.R. and Grood, E.S., 1987, Why an Anterolateral Laxity or Anteromedial Laxity is not a Diagnostic Entity, Chapter 12 in Instructional Course Lectures, Volume XXXVI; American Academy of Orthopaedic Surgeons.

Use of pivot shift

The pivot shift test produced the greatest amount of subluxation of the lateral tibiofemoral compartment (Noyes et al. 1983a). The subjective difference in the quality of the pivot shift phenomena may be used to grade anterior subluxations from a qualitative standpoint (Table 2). Our results indicate that a positive pivot shift test indicates an anterior subluxation of both the medial and lateral tibiofemoral compartments.

Conclusions

1. Resecting the anterior cruciate ligament alone produced a 100 percent increase in total anteroposterior translation, whereas there was only a 15 to 20 percent increase in internal-external tibial rotation.

2. Even in the pivot shift type of tests there is a greater increase in anterior tibial translation than internal tibial rotation.

3. During the anterior displacement (drawer) tests at 15° to 20° knee flexion, the examiner should estimate the maximum amount of anterior displacement of both the medial and lateral tibial condyles.

4. Traditional anterior displacement tests at 90° knee flexion involve abnormal motions of less magnitude than at 20°, and are less sensitive in detecting ligament defects.

5. The classification of ligamentous injuries should be based on which ligamentous and capsular structures are injured rather than the pathologic motions that exist. Stress tests represent clinical signs rather than diagnostic entities.

6. The interpretation of clinical stress tests requires a 3-dimensional framework specifying 1) which of the three rotations or three translations are increased; 2) the knee position where the test is conducted, because stress limits are strongly dependent on the starting position; and 3) the subluxation (direction and magnitude) of the medial and lateral tibial condyles separately. The rotatory subluxation can be simplified by expressing the translation of each tibial condyle.

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