We have measured anterior and posterior displacement in 563 normal knees and 487 knees with chronic deficiency of the anterior cruciate ligament (ACL). We performed stress radiography using a simple apparatus which maintained the knee at 20° of flexion while a 9 kg load was applied. There was no significant difference in posterior translation dependent on the condition of the ACL. Measurement of anterior translation in the medial compartment proved to be more reliable than in the lateral compartment for the diagnosis of rupture of the ACL, with better specificity, sensitivity and predictive values.

We have classified anterior laxity based on the differential anterior translation of the medial compartment and identified four grades in each of which we can further distinguish four subgrades for laxity of the lateral compartment. Within each of these subgroups, either internal or external rotation may dominate and sometimes there is a major translation of both compartments.

Radiological evaluation of displacement of the knee in 20° of flexion provides conclusive evidence of rupture of the ACL. A detailed study of pathological displacement is the basis for a classification of laxity. It is then possible to decide for each type of laxity, the surgical treatment which is specifically adapted to the lesion, and to define a reference value for judging outcome.

The anterior cruciate ligament (ACL) is the main restraint of anterior tibial translation. The experiments of Butler, Noyes and Grood have shown that whatever the angle of knee flexion, the ACL absorbs nearly 90% of the force causing translation. Experimentally, Fukubayashi et al demonstrated that division of the ACL produced an increase in anterior tibial translation with no change in posterior movement. Gollehon, Torzilli and Warren analysed coupled internal-external rotation of the tibia. When an anterior force was applied to the tibia of a knee with intact ligaments, internal rotation occurred. A posterior force produced external rotation. These movements, rotations with coupled anterior and posterior translation, are greater in flexion than near extension. Markolf, Kochan and Amstutz found this increase to be more marked at an angle of 20° of flexion than at full extension or at 90° of flexion. Torg, Conrad and Kalen introduced the Lachman test, which has been shown to be the most reliable diagnostic sign of a rupture of the ACL.

Measurement of the translation of the tibia in respect of the femur is not possible using clinical tests, which are subjective, imprecise and rarely reproducible. Stress radiography at 90° of flexion was used by Kennedy and Fowler in 1971 and by Jacobsen in 1976. We have developed a method of measuring physiological joint play and increased coupled knee movement. Since 1972 we have employed a technique of manual measurement of stress radiography with maximum forces at 70° and at 20° of flexion. The test is performed at 20° of flexion with a fixed load applied to the thigh. The current radiological techniques are now simpler and more reliable, especially when performed at 20° of flexion.

Several instrumental techniques have been developed but are rarely used because of their complexity, except for those of Daniel et al and Sherman, Markof and Ferkel.

Our study describes the dynamic radiological protocol for quantifying anterior and posterior displacements at an angle of 20° of flexion using a load of 9 kg. The measurements of anterior and of posterior translation of the compartments of the knee are the basis of a classification.

**Patients and Methods**

The study group comprised 1050 knees of which 487 were proven to have a ruptured ACL. The contralateral knees were used as a control group as well as 76 normal knees from a...
Further 38 subjects investigated using an identical protocol to assess laxity. All the knees were radiographed under a 9 kg load to reveal anterior and posterior translation.

The subjects were aged between 16 and 50 years and had no previous surgery or bucket-handle meniscal tears; 70% were male. Their mean age was 27.6 ± 9 years. In the study period of less than 30 days 2100 radiographs were assessed and 4200 measurements made by a single observer (JLL) who was blind as to all previous measurements. Intraclass correlation was used to evaluate interobserver reliability by random selection of 50 patients (50 injured and 50 non-injured knees) from the group. For the interobserver reliability, anterior translation of the medial and of the lateral compartments was measured by three different observers, two senior surgeons and one resident. For intraobserver reliability one of the previous observers measured the same subjects twice.

Table I gives the details of intra- and interobserver intra-class correlations. All values include 95% confidence intervals. According to Fleiss the reliability of these intra- and interobservations is excellent.

Statistical analysis was performed using the SPSS software (SPSS Inc). ACC software was used to construct the 'receive operating characteristics' (ROC) curve and to choose the optimal cut-off point. The mean SD and range of compartmental anterior and posterior displacement were calculated. Student’s t-test was used for paired comparisons.

### Table I

<table>
<thead>
<tr>
<th></th>
<th>Normal (n = 50)</th>
<th>ACL-deficient (n = 50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATMC*</td>
<td>0.91 (0.85 to 0.95)</td>
<td>0.95 (0.90 to 0.98)</td>
</tr>
<tr>
<td></td>
<td>0.97 (0.95 to 0.98)</td>
<td>0.98 (0.94 to 0.98)</td>
</tr>
<tr>
<td>ATLC†</td>
<td>0.92 (0.85 to 0.95)</td>
<td>0.92 (0.85 to 0.95)</td>
</tr>
<tr>
<td></td>
<td>0.93 (0.89 to 0.96)</td>
<td>0.95 (0.92 to 0.97)</td>
</tr>
</tbody>
</table>

*anterior translation of the medial compartment
†anterior translation of the lateral compartment

### Radiological technique

**Anterior translation.** The patient lies with his buttocks on the edge of the table (Fig. 1a). The calf is placed on a rigid support (I), the thigh is free and the foot rests on a second support (II) which is height-adjustable and secured by a strap. The opposite limb rests on a stool at a lower level. The knee under test is flexed to 20° by the fixed inclination of the splint under the calf. The 9 kg load is applied to the thigh using a strap placed anteriorly above the upper pole of the patella. This load therefore pushes the distal femur posteriorly, while the proximal tibia is fully supported by the splint, producing anterior displacement of the tibia. The x-ray cassette is placed medial to the knee and the x-ray beam is centred on the knee, one metre from the cassette.

**Posterior translation.** The patient is placed on the table as before (Fig. 1b). The support (I) is rotated so that the thigh rests on the splint, the distal edge of which is placed just above the knee. The leg is free and the ankle and the foot are in the same position as for the anterior drawer test. The knee to be tested is flexed to 20° by the fixed inclination of the splint. The 9 kg load is applied to the leg by a strap placed on the tibial tubercle. This load thus depresses the proximal tibia while the distal femur is held in place by the splint, causing posterior tibial displacement. The radiological technique is identical to that for anterior translation.

### Radiological analysis

The bone contours of the medial and lateral femoral condyles are different. The medial condyle has a small notch at its junction with the trochlea and is more anterior. It is rounded at its posterior end and the adductor tubercle may be visible above its posterior edge. The condylotrochlear notch of the lateral condyle is larger, deeper and more posterior; its posterior edge is more angular. The posterior edge of the medial tibial plateau is vertical and the junction with its superior edge makes a right angle. The posterior edge of the lateral tibial plateau is rounded and has a gentle slope with the posterior tibial spine.

The zero position from which displacement is to be
measured, is the relative alignment of the compartments of the knee in all planes and around all axes when no weight is applied. When a load is applied anteriorly on the thigh there is anterior translation from the zero position. Posterior translation is the movement from the zero position to the final posterior position.

We have used the posterior tibial cortex as the reference line, as recommended by Jacobsen. The respective positions of the medial and lateral compartments of the femur and tibia are determined using two lines parallel to the reference line which pass through the most posterior points of the condyles and the most posterior aspects of the medial and lateral tibial plateaux. The radiographic zero is dictated by the observation made in the sagittal plane on a knee flexed to 20° in a standard radiograph. The tangent to the posterior aspect of the medial femoral condyle running parallel to the posterior tibial cortex is also tangential to the posterior aspect of the medial tibial plateau. This is a constant observation, irrespective of internal and external rotation of the tibia. Compartmental alignment in the sagittal plane at 20° of flexion was therefore defined as the radiographic zero. For the lateral femorotibial compartment we chose as the zero position, the superimposition of posterior tangents constructed at the subchondral bone level.

The anterior or posterior displacements correspond to the distance in millimetres between the two lines in each compartment after anterior or posterior loading (Fig. 2). Four measurements are obtained for each knee: anterior translation of the medial (ATMC) and lateral compartments (ATLC) and posterior translation of the medial (PTMC) and the lateral compartments (PTLC). It is then possible to calculate the differential values between the injured and the non-injured knee of the same patient, that is the pathological laxity (respectively PATMC, PATLC, PPTMC and PPTLC).

The zero position differs from the starting reference position used in clinical evaluation and in instrumented clinical testing and arthrometric measurements, because the weight of the leg and the anteriorly superimposed load of the instrumented testing device affect the standing reference position with the patient supine, the thigh supported and the quadriceps relaxed.

Results

The right to left difference for normal subjects was 0.5 ± 0.4 mm for ATMC, 1.2 ± 0.4 for ATLC, 1.1 ± 0.7 for PTMC and 1.5 ± 1.2 for PTLC. There was no statistical difference between men and women in any of the measurements.

Anterior translation. The mean ATMC for non-injured knees was 2.1 ± 2.6 mm (-6 to +11) and for ruptured knees 10.4 ± 4.3 mm (0 to 25) (p < 0.001). The mean PATMC was 7.3 ± 4.8 mm (-3 to +24). The mean ATLC for non-injured knees was 10.5 ± 3.5 mm (1 to 23) and for injured knees 18.47 ± 5.1 mm (2 to 33) (p < 0.001). The mean PATLC was 7.9 ± 5.8 mm (-5 to +23).

Posterior translation. The mean PTMC for non-injured knees was 2.1 ± 2.9 mm (-6 to +12) and for injured knees 1.7 ± 2.9 (-9 to +10). The mean PPTMC was 0.1 ± 3.2 mm (-9 to +7). The mean PTLC for non-injured knees was 1.8 ± 3.8 mm (-9 to +14) and for injured knees 1.1 ± 4.1 mm (-12 to +13). The mean PPTLC was -0.4 ± 5.1 mm (-15 to +14). There was no significant correlation between the paired values of the pathological posterior translations of both compartments and between the values of the posterior translation dependent on the condition of the ACL.

Diagnostic test of ACL rupture. The measurements of ATMC and ATLC are reliable for the diagnosis of rupture of the ACL; the area under the ROC curve for ATMC and ATLC was greater than 0.90 (Fig. 3). The optimal cut-off points for ATMC and ATLC were, respectively, 6 and 11.5 mm. For ATMC, 90% of non-injured knees do not exceed 6 mm (specificity) compared with 87% for ATLC. For ATMC, 87% of non-injured knees do not exceed 11.5 mm (sensitivity) compared with 79% for ATLC.

It follows that ATMC is relatively more reliable than ATLC for the diagnosis of rupture of the ACL. For these subjects, the positive and negative predictive values for ATMC were 89% and 85%, respectively, contrasting with 88% and 82% for ATLC.

Classification of anterior ACL-deficient knees. A classification of anterior knee laxity may be based on the displacement of the medial side. The differential ATMC can
be separated into four grades: grade 1, less than 5 mm; grade 2, 5 to 8 mm; grade 3, 8 to 11 mm; and grade 4, more than 11 mm. In each group we can further distinguish four subgrades (A, B, C, D) for lateral compartment laxity, using the same ranges. This choice is arbitrary but the mean differential ATMC has identical values to the mean differential ATLC and both have the same ranges (Table I).

These four grades of laxity can be isolated, based on measurements of the medial compartment, with four subgrades in each group. In Table II, 16 categories are represented with the incidence of the cases expressed as percentages.

In grade 1, the lateral compartment laxity may be equivalent to the medial side (1A). If there are lateral associated lesions, internal rotation of the tibia on the femur increases gradually (grades 1B, 1C and 1D, Fig. 4).

In grade 2, the ATMC is greater (5 to 8 mm); there are knees which have a minor lateral laxity (grade 2A) and the tibia rotates externally on the femur. Lateral play may be equivalent to medial play without rotation (2B), or greater leading to internal tibial rotation (2C and 2D).

In grades 3 and 4, the large anterior translation in the medial compartment indicates a lesion of the ACL with possible damage to the postero-medial corner. External rotation of the tibia can be observed in many cases (3A, 3B, 4A, 4B, 4C). In grades 3C, 3D and 4D there is extensive translation of both compartments.

**Discussion**

Radiological methods have been recommended because they are easy to use and usually involve no sophisticated apparatus. The posteroanterior glide depends for a great part on the position of the knee when it is tested. In the near extended position (between 10° and 20° of flexion), there is less coupled anteroposterior translation/rotation than at 70° or 90°. We chose 20° of flexion to compare stress radiological and arthrometric measurements because it is the position for the Lachman test.

The coupled anterior/translation internal rotation of the tibia with respect to the femur supports the concept that the ACL is an important primary restraint to anterior displacement and a major secondary restraint to internal rotation. Our findings with stress radiographs in ACL-deficient knees are similar to those reported by Stäubli. Differing applied loads cause significant variations in the results. The displacements are moderate and occasionally zero for the non-injured knee with a load of 3 kg but a force of 20 kg, as recommended by Stäubli et al,13 yields results compatible with our findings for injured and normal knees. The choice of a load of 9 kg therefore seems a satisfactory compromise for the sensitivity of the test and the patient's comfort. Nevertheless, it is essential to carry out the examination using a non-variable load, unlike the active technique recommended by Dejour et al using quadriceps contraction, which gave lower values.

Our results for anterior translation are comparable with those obtained with more sophisticated apparatus which vary between 3 and 10 mm. The values for pathological knees are difficult to compare from one study to another because of differences between the study groups.

Our findings are in agreement with those of Hooper and Stäubli et al and Stäubli, and show a clear increase in the anterior displacement of the two compartments of the knee when the ACL is ruptured (p < 0.001).

In ACL-deficient knees there is increased anterolateral subluxation of the tibia on the femur. This finding supports the concept of dynamic subluxation/reduction testing with coupled anterior translational forces and internal rotational moments being applied to the tibia.

The greater the applied external force and moment, the greater is the magnitude of displacement. Dahlstedt and Dalén compared 41 patients who were not anaesthetised with ten who were and found significant increases in transla-
tion when the patient was under general anaesthesia. These data confirm our findings with arthrometric measurements but for this study we chose measurements without anaesthesia to compare assessments before and after surgery.

Stress radiography has one important advantage in the detailed study of pathological movement since the displacements of the medial and lateral compartments can be identified separately. This provides the diagnosis of lesions of the posteromedial corner which allow a marked anterior translation, predominantly in the medial compartment, whereas isolated rupture of the ACL gives a moderate anterior translation, predominantly in the lateral compartment. In the same way it is possible to detect a lesion of the posterolateral corner by an increase of the translation in the lateral compartment. This information will influence the choice of surgical technique.

One important observation is that the posterior position corresponds to the starting position during clinical tests and arthrometric measurements. This posterior displacement is not influenced by the rupture of the ACL, but the sum of posterior and anterior play is important when posterior displacement affects function. Neither the Lachman test nor arthrometric measurement can quantify anterior and posterior displacement separately.

A major source of inaccuracy is the precise identification of the subchondral bony landmarks on radiographs with some degree of malrotation and superimposition of bony contours. We have shown that the intra- and interobserver difference is minimal. Although the tube-to-film distance is standardised, the film-to-object distance varies for the medial and lateral compartments creating variables of radiological magnification and parallax.

The surgeon’s task in selecting the most appropriate operation to correct the structural damage and to restore function can be based on objective data, a valuable adjunct in assessing combined anteroposterior instability. After considering

![Figures](http://example.com/fig4a.png) ![Figures](http://example.com/fig4b.png) ![Figures](http://example.com/fig4c.png) ![Figures](http://example.com/fig4d.png)

Classification of anterior laxity based on ATMC and ATLC. When ATLC is greater than ATMC, the tibia rotates internally on the femur (e.g., in grades 1B, 1C and 1D) and when ATLC is less the tibia rotates externally (e.g., in grades 4A, 4B and 4C). The four grades (a to d) of anterior laxity are presented with distribution (%) of cases in each category.
the differing types of laxity, specific plans for operation can be made.

In grades 1 and 2, when there is a subgrade A or B translation of the lateral side (37% of patients), isolated reconstruction of the ACL can be recommended. With subgrade C and D, translation of the lateral side (19% of the patients), additional lateral, extra-articular reconstruction may be wise.

In grades 3 and 4, when the differential ATMC is more than 8 mm and the differential ATLC more than 8 mm (subgrades C and D), a complementary medial reconstruction is an option. The long-term results of coupled ACL and lateral extra-articular reconstruction will demonstrate whether anterior radiological measurements could be improved in these categories and will establish the limits of that hypothetical proposition.

Conclusions

Stress radiography with constant forces at precise angles allows determination of compartmental translation in the anterior direction with respect to the anatomical zero position. By visualising the displacement of each compartment, a detailed study of their anterior pathological translations allows classification of the laxity.

A single preoperative examination, however, cannot confirm if there is to be progressive deterioration with time for a given patient. It is none the less possible to define, for each type of laxity, a specific surgical treatment which is adapted to the lesion and provides a reference value from which to assess the effectiveness of management.

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.

References