RADIOLOGICAL ASSESSMENT OF ANTERIOR CRUCIATE LIGAMENT DEFICIENCY

A NEW TECHNIQUE

GARY J. HOOPER

From Christchurch Public Hospital, New Zealand

A new method of demonstrating sagittal laxity in the anterior cruciate-deficient knee is described. Seventy such knees were compared to 70 normal knees. Sagittal laxity was recorded as the average displacement of the medial and lateral femoral condyles. This displacement index was significantly different between the two groups of knees ($P < 0.0001$). A range for normal and abnormal knees is discussed. Quantitative assessment of the degree of sagittal laxity by clinical evaluation is shown to be unreliable. Only the pivot-shift test demonstrated any significant correlation with the amount of sagittal displacement ($P < 0.05$).

Assessment of the anterior cruciate-deficient knee has been considered by numerous authors over the past decade. Several new clinical tests to improve our diagnosis of sagittal instability have been developed and attempts have been made to measure the displacement (Hughston *et al.* 1976; Slocum *et al.* 1976; Galway and MacIntosh 1980). Most of these clinical methods have been largely unsuccessful, however, because of the difficulty in determining the degree of instability accurately.

"Gonylaxometers" (Jacobsen 1981) have been used to try and overcome this difficulty, but have their own errors, mainly due to soft-tissue movement. The most reliable and reproducible assessments of sagittal laxity to date have been by radiographic methods (Kennedy and Fowler 1971; Jacobsen 1976; Levén 1977, 1978; McPhee and Fraser 1980-81; Jacobsen 1981). All of these have involved the use of a gonylaxometer to stress the knee before radiological examination; but the size, expense and relatively clumsy nature of the gonylaxometer restricts its clinical usefulness.

The maximum sagittal displacement occurs with the knee flexed 20° (Markolf, Mensch and Amstutz 1976). When an anterior cruciate-deficient knee is held in this position, with the thigh unsupported, the weight of the thigh causes the femoral condyles to displace posteriorly relative to the tibial plateaux (the reverse of the posterior sag sign), and this displacement can be documented radiologically. The weight of the unsupported thigh sup-

plies sufficient force about the knee to stress it, making the use of a gonylaxometer unnecessary, which in turn makes the method more usable clinically.

The objectives of this present study were: to document the effectiveness of this method of assessing sagittal laxity by comparing normal knees to anterior cruciate-deficient knees; to describe a range of normal sagittal displacement for knees using this method; and to compare the clinical assessment of the degree of instability with the radiological findings.

METHOD AND MATERIAL

Radiological method. The patient was positioned supine with the injured leg held on a support, 30 cm above the trolley, so that the knee was flexed approximately 20°. The thigh was unsupported and a 3 kg standard weight (in the form of a sandbag) was placed on the anterior thigh (just proximal to the patella) to increase the displacing force. This was the only stress applied to the knee.

In positioning the patient it was important to have the patella directed upwards, to avoid excessive rotation; and to have the patient as relaxed and comfortable as possible, to avoid excessive muscle spasm. The film cassette was always placed on the lateral side of the knee, perpendicular to the beam which was directed towards the medial side. The beam was horizontal to both the knee joint and to the floor (Fig. 1). The distance from the film cassette to the outer filter of the tube was a constant one metre.

Once a lateral view had been taken in this "stressed" position the patient was positioned on his side to have a "standard" lateral view taken. The film to tube distance remained 1 m, the knee was flexed to 20° and the beam was again directed towards the medial side, perpendicu-

G. J. Hooper, MBBCh, Orthopaedic Registrar
Orthopaedic Department, Christchurch Public Hospital, Private Bag,
Christchurch, New Zealand.

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0301 620X 86 2044 \$2.00

lar to the knee joint (Fig. 2). The stressed and standard views were then measured and compared.

Radiological measurement. The radiological anatomy of the knee has been described in detail giving consistent femoral and tibial reference points (both medial and lateral) on the lateral radiograph.

Jacobsen (1981) identified the lateral femoral condyle as larger and flatter, with the condylo-patellar sulcus (or limiting groove) in the middle of the curve of the condyle; whereas the medial femoral condyle had its limiting groove situated more anteriorly. The tibial plateau could be distinguished by following the tibial (intercondylar) tubercles posteriorly. The lateral tubercle continued backwards in a convex arch to the narrow and more pointed lateral tibial plateau (Fig. 3); whereas the

Fig. 1

Fig. 2

Figure 1—Knee in the "stressed" lateral position. Note the sandbag on the thigh to increase the posterior displacing force exerted on the femur. Figure 2—Knee in the "standard" lateral position.

medial tubercle sloped backwards in a concave manner to the larger and squarer medial tibial plateau.

Using these landmarks, and a line from the posterior aspect of the medial tibial plateau to the anterior aspect of the medial tubercle as the line parallel to the joint, the displacement of the femoral condyles relative to the tibial plateaux could be measured. To do this a modification of Kennedy and Fowler's (1971) method was applied.

Two transparent templates with two lines at right angles to each other were used. The first template was placed on the radiograph with one of the lines parallel to the joint and the other line placed on the most posterior aspect of a femoral condyle. The other template was then placed on the radiograph with one of the lines parallel to the joint and the other on the posterior aspect of the appropriate tibial plateau. Then the displacement of the femoral condyle from its respective tibial plateau could be measured. If the femoral condyle was anterior to the tibial plateau then the measurement was said to be negative, and if the femoral condyle was posterior to the tibial plateau the measurement was said to be positive (Figs 4 and 5).

Displacement for each knee was recorded in the stressed and standard positions, and the medial and lateral condylar displacements were each calculated by subtracting the standard from the stressed. The average of these two displacements was termed the displacement index and was calculated for each knee. All measurements were recorded "blind" and rounded to the nearest 1.0 mm.

Clinical material. Seventy knees, all diagnosed operatively as anterior cruciate deficient, were compared to 70 normal knees. All knees were examined by a single examiner in a standard manner.

Fig. 3

Standard lateral radiograph of the knee with the lateral femoral condyle and the lateral tibial plateau outlined.

Fig. 4

Fig. 5

Figure 4—Standard lateral radiograph of the knee with two lines drawn on the posterior aspects of the lateral femoral condyle (*f*) and the lateral tibial plateau (*t*) at right angles to the joint. Because the femoral condyle is situated anterior to the tibial plateau the measurement is negative. Figure 5—Stressed lateral radiograph of the same knee. Now the femoral condyle (*f*) is displaced posteriorly with respect to the tibial plateau (*t*) to give a significant positive sagittal displacement.

Sagittal instability was assessed by both the anterior drawer test and by the Lachman test. The anterior drawer test was performed in neutral, 20° medial and 20° lateral rotation. It was graded 0 to 3+. The Lachman test, which was positive in all the injured knees, was graded according to whether there was a definite end-point as opposed to a soft or "mushy" end-point.

Anterolateral rotatory instability was assessed by the pivot-shift test. It was graded "nil" if it was negative, a "slide" if there was a subluxation which reduced in a gentle manner, a "jerk" if there was a sudden reduction and "fear" if the examination could not be carried out due to the patient's apprehension.

RESULTS

Clinical. There were over twice as many males as females (2.5:1); the average age was 23 years (range 14 to 60). The initial injury occurred most frequently while playing rugby (30/70) and only eight (8/70) occurred during non-sporting activities. Both knees were equally affected.

Instability was the most common symptom, followed by pain and locking. There were 12 acute injuries of which three had an associated tear of the medial collateral ligament. In all the knees with chronic injuries (58/70) no other ligamentous laxity was demonstrated. The anterior drawer sign ranged from 0 to 3+ in neutral rotation; 20° medial rotation increased the drawer sign in only four knees, whereas 20° lateral rotation increased it in all the knees. All injured knees had a positive Lachman sign; 36 had a definite end-point and 34 did not. The pivot-shift test was negative in 3, was graded "slide" in 30, "jerk" in 27 and "fear" in 10.

Radiological. Normal displacement of the medial con-

dyle ranged from -7 mm to +8 mm, with a mean of +1.7 mm; displacement of the lateral condyle ranged from -2 mm to +9 mm with a mean of 2.4 mm. The displacement index for normal knees ranged from -2 mm to +6 mm with a mean of +2.3 mm (Table I and Fig. 6).

In the injured knees the displacement of the medial condyle ranged from -2 mm to +19 mm with a mean of +8.3 mm compared to the displacement of the lateral condyle of 0 mm to +24 mm with a mean of +11.8 mm. The displacement index ranged from +4 mm to +19 mm with a mean of 10.3 mm (Table II and Fig. 7). The displacements of both the medial and lateral condyle were highly significant when compared with those of the uninjured knee ($P < 0.0001$ Student's *t*-test).

Fifty-three patients with an anterior cruciate-deficient knee had a normal contralateral knee. When comparing the differences between knees in these patients the medial side had a mean difference of 6.2 mm, and the lateral side a mean difference of 8.2 mm—both results being outside the maximal difference found between pairs of knees in normal uninjured individuals; both are highly significant ($P < 0.0001$ *t*-test for matched pairs).

Each clinical parameter was then correlated with the radiological findings. The most interesting results came from comparing the pivot-shift test. When the results of this test were divided into "slide" (41%) and "jerk" (39%) there was a significant correlation between the displacement of the lateral condyle and those knees that "jerked" ($P < 0.05$; Table III).

Table I. Sagittal displacement in uninjured knees

Displacement	Range (mm)	Mean (mm)
Medial condyle	-7 to +8	+1.7
Lateral condyle	-2 to +9	+2.4
Displacement index	-2 to +6	+2.3

The ranges have been rounded to the nearest millimetre

Table II. Sagittal displacement in the anterior cruciate-deficient knees

Displacement	Range (mm)	Mean (mm)
Medial condyle	-2 to +19	+8.3
Lateral condyle	0 to +24	+11.8
Displacement index	+4 to +19	+10.3

Table III. Comparison between the amount of sagittal displacement and the clinical severity as judged by the pivot-shift test

Pivot shift	Number	Mean lateral displacement (mm)	Mean displacement index (mm)
Slide	30	10.5	9.5
Jerk	27	13.5 ($P < 0.05$)	11

Experimental errors

Errors of measurement. Thirty knees, which had been previously measured, were randomly selected and re-measured using a blind technique. The mean error was 1 mm, with 93% having 1.5 mm error or less on the medial side, and 83% having 1.5 mm error or less on the lateral side.

Radiological errors. Error due to magnification could be ignored because all the views were taken by the same method in which the medial side was constantly magnified by approximately 10%.

Large discrepancies can be caused by changes in rotation and it is emphasised that every effort should be made to position the knee in neutral rotation. The lateral femoral condyle displaced further than the medial in the anterior cruciate-deficient knee and therefore obvious

rotation occurred about the coronal plane. The maximal difference in displacement between the medial and lateral sides was 17 mm, representing approximately 15° of rotation. The average difference in displacement was 5 mm, or 5° of rotation.

Eight knees were then examined with the beam rotated 0°, 10° and 15° about the anteroposterior plane to determine the error due to rotation. Between 0° and 10° the error on measuring the displacement of the lateral condyle was 1 mm, and of the medial condyle was 1.5 mm. Between 0° and 15° the error on the lateral side was 1 mm compared to 2 mm on the medial side.

From these results the total experimental error was approximately ± 2 mm. This error was slightly less when measuring the lateral side. The error did not alter the significance of the results.

UNINJURED KNEE

Fig. 6

INJURED KNEE

Fig. 7

Figure 6—Histogram showing the displacement of medial and lateral femoral condyles in normal knees. Figure 7—Histogram showing the displacement of medial and lateral femoral condyles in anterior cruciate-deficient knees.

DISCUSSION

Precise measurement of sagittal laxity in the anterior cruciate-deficient knee is important both in improving diagnosis and in the constant re-evaluation of treatment. However, up to now, most methods of measuring instability have been impracticable clinically. This present method is easily adaptable to most clinical settings and has been shown to be both effective and reproducible. The mean displacement index for normal knees was 2 mm compared to 10 mm for the anterior cruciate-deficient knee. These displacements are less than those recorded in previous studies but can be explained by the relatively small force applied across the knee. In normal knees Torzilli, Greenberg and Insall (1981) demonstrated 3.8 mm displacement with a force of 67 newtons and 6.7 mm with 134 newtons; and Markolf, Kochan and Amstutz (1984) demonstrated 4.3 mm with 100 newtons.

Fig. 8

The difference in displacement index between the anterior cruciate-deficient knee and the normal contralateral knee in 53 patients.

Of more clinical relevance was the range of normal sagittal displacement. The cruciate-deficient knees had a minimum displacement index of 4 mm and so any knee with a displacement less than this should be considered normal. The normal knees examined had a maximum displacement index of 6 mm. This leaves a range between 4 mm and 6 mm where the knee is probably normal. If the index is more than 6 mm the knee should be considered abnormal

Abnormal sagittal laxity may be found when comparing an injured knee to the contralateral normal knee, but only if the difference is higher than the maximal difference between normal knees, which is 5 mm (Markolf *et al.* 1976, 1984). Thus if the difference in the displacement index between the two knees is more than 5 mm then the injured knee should be considered abnormal (Fig. 8).

Previous clinical and radiological studies have demonstrated that the lateral compartment of the normal knee is more mobile in the sagittal direction than is the medial side (Jacobsen 1976; Markolf *et al.* 1976; Levén 1977, 1978; Jacobsen 1981; Markolf *et al.* 1984), and this difference is increased in the anterior cruciate-deficient knee. This study supported these findings with a mean of 0.7 mm more lateral movement in the normal

knee and 3.5 mm more in the injured knee. These mean displacements were less than those reported by others and can be explained, once again, by the smaller force applied to the knee.

Clinical signs are notoriously difficult to measure and our study emphasised this point. The radiological method employed was similar to a "passive" Lachman test, and so we might expect a correlation between radiological sagittal laxity and the objective grades of the Lachman test. However, the results were not significant. The only clinical test which correlated to the radiological findings was the lateral displacement in the pivot shift ($P < 0.05$). Intuitively we would expect the sagittal laxity of the lateral compartment to be greater in those knees that "jerked" and this may indeed be an accurate means of measuring clinically the degree of laxity.

Conclusion. This radiological method is inexpensive, easy to perform and comfortable for the patients. It has been used successfully in the knee with an acute injury and involves the taking of only one additional radiograph. The surgeon obtains a permanent quantitative assessment of the sagittal laxity, with a comparison of both the medial and lateral components. This information supplements the clinical data, helping initially with the diagnosis and later in the planning of suitable reconstructive procedures. This record may also enable better assessment of operative procedures, both in the early and later phases, and ultimately may help the accuracy of prognosis.

I would like to thank Professor W. Gillespie for his help in preparing this manuscript; and the clerical, radiological and nursing staff of the orthopaedic department for giving their time and energy to this study.

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