Instability after anterior cruciate ligament rupture

Measurements of sagittal laxity compared in 11 cases

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Manual tests and 2 external devices were used together with roentgen stereophotogrammetry (RSA) and an active weight-bearing radiographic method to measure the sagittal laxity in 11 knees with anterior-cruciate-ligament rupture. In 5 knees no ligament surgery had been performed (unstable knees) and in 6 knees a reconstruction had been performed one year before the examination (stable knees). There were positive correlations between all methods, including the manual tests when all knees, both stable and unstable, were analyzed together. However, the mean values of the total displacement differed between the methods, especially when comparing the weight-bearing radiographs with the three other methods. Some knees with substantial displacement during passive loading did not show any displacement when weight bearing; the measurements thus depended on both the ligamentous laxity and the patient's neuromuscular control of the joint. When the stable knees were analyzed separately, higher mean values were recorded with the external devices than with RSA using 180 N load. This could be explained by an error from soft tissue deformation which added to the skeletal displacement when the external devices were used.

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We analyzed 4 different methods of measuring the sagittal knee laxity including their relation to commonly used clinical tests in patients with chronic anterior cruciate ligament injuries, where some were examined prior to and some after reconstructive surgery.

Patients (Table 1)

Preoperative group. 5 patients were measured after an arthroscopic evaluation of the joint where meniscal surgery, if necessary, was performed. Insufficiency of the anterior and an intact posterior cruciate ligament were verified in all knees. All patients complained of instability problems with episodes of giving way or an unacceptable activity level, despite a period of neuromuscular rehabilitation. The mean age was 24 (16–32) years and time from injury to examination was 4 (1–9) years. There were 2 women and 3 right knees. Tantalum RSA markers were inserted into the distal femur and the proximal tibia by cannulas and a spring-loaded pistol.

Postoperative group. 6 consecutive patients had had a reconstruction of the anterior cruciate ligament with a free bone-tendon-bone graft from the patellar ligament one year before the measurements. Prior to surgery all patients had the same impairment and disability as the preoperative group, and relief of the instability problems was achieved after surgery. The mean age was 26 (18–28) years and time from injury was 4 (2–6) years. There was 1 woman and 2 right knees. At the operation, tantalum markers were implanted in the distal femur and proximal tibia including separate markers in the bony ends of the graft. The posterior cruciate ligament was intact in all cases.

All patients in both groups had an uninjured contralateral knee.

Methods

The patients were examined using all the methods in random order on the same day. The results of the measurements with each method were not known by the other examiners. All examiners were well experienced with their specific method.

A. Manual examination. The Lachman test (Torg et al. 1976), the drawer test in 90 degrees of flexion in

Table 1. Sagittal laxity in 11 knees

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	88	M	1	–	3	2	3	17.0	4.3	10	6	9.0	24.5	8.0	17	9	12.1	10
2	16	M	1	–	2	2	2	13.3	8.3	12	6	13.1	18.0	11.4	16	6	19.4	10
3	12	F	2	–	2	2	2	19.2	16.6	17	7	15.9	26.7	24.1	22	13	14.2	10
4	42	F	1	–	2	3	3	14.4	8.9	12	8	9.2	19.2	14.8	15	12	13.8	7
5	70	M	2	–	2	2	1	7.2	5.6	12	5	8.6	12.6	8.2	17	9	–	0
6	68	M	1	13	1	0	1	8.9	7.0	2	7	7.4	12.7	11.4	7	11	4.4	4
7	24	M	1	13	1	0	1	11.3	7.1	7	6	–	16.0	10.8	12	9	7.2	3
8	38	M	2	13	0	0	1	12.9	10.1	8	4	5.2	9.2	13.8	10	7	5.8	0
9	32	F	2	13	0	0	1	4.5	8.4	4	4	3.6	8.2	11.6	8	7	3.0	0
10	42	M	2	14	1	0	0	9.7	7.6	8	5	8.4	13.3	12.0	12	7	7.4	3
11	58	M	2	13	1	0	0	9.9	10.6	6	4	2.6	15.4	13.6	12	7	4.7	0

1 Patient order
2 Months from injury
3 Sex
4 Injured side
  1 right
  2 left
5 Months after surgery
6 Lachman test as described in text
7 Flexion-rotation-drawer test
8 Drawer test in 90° flexion
9 CA 4000 90 N injured (mm)
10 uninjured (mm)
11 Stryker 90 N injured (mm)
12 uninjured (mm)
13 RSA 90 N (mm)
14 CA 4000 180 N injured(mm)
15 uninjured (mm)
16 Stryker 180 N injured (mm)
17 uninjured(mm)
18 RSA 180 N (mm)
19 Radiographic weight bearing (mm)

neutral, external and internal rotation were used as well as the flexion-rotation-drawer test (Noyes et al. 1988). The tests were performed on both knees and the laxity was graded with reference to the normal knee as + < 5 mm motion, ++ 5–10 mm motion and +++ > 10 mm in the sagittal tests. The flexion-rotation-drawer test was graded + (subtle slip), ++ (obvious jerk) and +++ (impingement).

The manual tests were carried out by one examiner (JG) without prior knowledge of the results of the instrumented measurements. The examiner had not been involved in the surgical treatment of the patients.

B. The Stryker laxity tester (Orthopedic System Inc., Hayward CA, U.S.A.) was used as described by Andersson and Gillquist (1990). The patient was sitting on an examination platform with both legs fixed and the knee flexed to 25 degrees and the flexion angle was measured with a liquid goniometer. The posterior and anterior displacements were measured at 90 and 180 N loads. Measurements were repeated until stable values were obtained, usually 2–3 times. The device did not constrain rotation of the tibia, but internal rotation was minimized by applying the force handle from the medial side during measurements of the anterior displacements. Posterior and anterior displacements were rounded off to the nearest millimeter, then added and referred to as total displacement. The test-retest correlation for total displacement has been found to be 0.8 for 180 N force and 0.7 for 90 N.

C. The CA4000 arthrometer (Orthopedic Systems Inc., Hayward, CA, U.S.A.) is a measuring device consisting of an examining chair, a goniometer chain and a force handle. Sampling of the force displacement curves was done by a microcomputer. The goniometer chain registered rotations of the tibia around three axes, and the anterior-posterior displacement of the tibia relative to the patella was simultaneously registered by another rotational potentiometer. A posterior/anterior force displacement curve was generated up to 180 N. The software reads values at 90 and 180 N in fractions of millimeters. Tibial rotation was not constrained but tests with excessive rotation could be discarded. The test-retest correlation for total displacement has been estimated at 0.95.

D. Roentgen stereophotogrammetric analysis (RSA) was used as described by Fridén et al. (1992a). Simultaneous calibration radiographs in extension were obtained in the frontal and lateral projections, with the knee inside a plexiglass calibration cage. Care was taken to place the leg in such a way that the tibia was parallel to the cage planes in both projections. After calibration, the cage was excluded leaving two reference planes, one in front of each film, to be exposed together with the patient markers. The leg was placed in the Lachman position, flexion 25 degrees, and the thigh was fixed in a brace and strapped to the examination table. The foot was prevented from moving anteriorly by a strap, while rotations were unconstrained. A standardized posterior force of 40 N and anterior forces of 90 and 180 N, applied perpendicularly to the tibia 6–8 cm distal to the femuro-tibial joint line in the Lachman position, using a pulley system, was subsequently applied. The patients were told to relax completely, and the different loads were applied for 20–30 sec.

The markers on the radiographs were made using a precision digitizing table (Hasselblad Engineering, precision 10 µm). On each radiograph comprising the calibration stereo pair, three imaginary points lay on a straight line passing through the center of the tibial eminence in the frontal plane, so that one point was at the center of the eminence while the others at the outermost extreme of each tibial condyle were also digitized. Using the X-ray program, the 3 D coordinates of the markers and imaginary points were obtained and by a point transfer routine in the RSA system the imaginary points were transferred to all other stereo pairs in that stress series. Motion of the tibia relative to the femur was obtained by the KINEMA routine based on rigid-body kinematics. The results where expressed in a cardinal axis coordinate system were the X-axis is transverse, Y-axis is vertical and the Z-axis is sagittal. The total anterior-posterior displacement was defined as the translation along the Z-axis of the mid-eminence point between the position during posterior load and the position achieved by each of the two anteriorly directed forces and expressed in the coordinate system rotated so that it was parallel to the tibia in the Lachman position, i.e., the sagittal Z-axis was perpendicular to the tibia and parallel to the applied forces. The accuracy of this RSA application in repeated measurements has been found to be 2.2 mm at the 95 confidence limit and the test-retest coefficient of correlation 0.93 (Fridén et al. 1992a).

E. Weight bearing to actively provoke the sagittal laxity was done under fluoroscopy control in 10-45 degrees of flexion and measurements of displacements were made on lateral radiographs using central measuring points (Egund et al. 1991). The lower leg was supported by a special frame, and the remote fluoroscopy unit made it possible to keep the femoral condyles superimposed during weight bearing in different degrees of flexion. The maximum displacement observed at fluoroscopy was documented on radiographs. The method has a reproducibility within 2 mm between repeated tests. However, some patients with displacements during passive testing have a neuromuscular control of the knee which does not allow any displacement to be demonstrated during weight bearing (Fridén et al. 1992b).

Statistics

Spearmans' rank correlation coefficient was used to analyze the correlation between the manual tests and the different measurements. Pearsons' coefficient of correlation was used for the instrumented measurements and a paired Students' t-test was used in the comparative analyses.

Results

There were positive correlations between all the clinical tests when compared with one another and also when these were compared with the four different methods of measurement in the total group of eleven patients. The patients with Lachman + had total anterior-posterior displacement from 2-16 mm with the external devices, 3-8 mm with RSA and 0-4 mm with the weight-bearing method. Lachman ++ corresponded to the range 7-27 mm with external devices, 9-19 mm with RSA and 0-10 mm with the weight-bearing radiographs.

The correlations were also significant between the CA 4000, Stryker, RSA and the weight-bearing radiographs except for Stryker 90 N versus the weight-bearing method (P 0.052).

The mean values, however, were different between all methods when comparing them at 90 N and 180 N provocative force, respectively, except for Stryker 90 N versus RSA 90 N (Figure 1, Table 2). The highest mean value was registered with CA 4000, 16 (8.2-27) mm and the lowest with weight-bearing radiographs 4.3 (0-10) mm.

In the *preoperative group* there were no differences in mean values except for the weight-bearing radiographs compared with the three other methods (Figure 2, Table 2). The highest mean value, 20 (13-27) mm, was registered with CA 4000 and the lowest 7.4 (0-10) mm with the weight-bearing radiographs.

In the *postoperative group* the displacements were smaller (Figure 3, Table 2), the mean values varying from 13 (8.2-16) mm with the CA 4000 to 1.7 (0-4) mm with the weight-bearing radiographic method. The mean value from the weight-bearing radiographs were lower than with the 3 other methods ($P < 0.01$). The CA 4000 readings were higher than Stryker when 90 N was used ($P < 0.05$) but not when the load was 180 N. No differences were found between the external devices and RSA using 90 N load, but both external devices had higher values than RSA when 180 N was used ($P < 0.01$).

Table 2. Total anteriorposterior displacement (mm). Mean *SD*

Method	Preoperative	Postoperative	Total group
Stryker 90 N	12.6 *2.6*	5.8 *2.4*	8.9 *4.3*
CA4000 90 N	14.2 *4.5*	9.5 *2.8*	11.6 *4.3*
RSA 90 N	11.2 *3.2*	5.4 *2.5*	8.3 *4.0*
X-ray weight b.	7.4 *4.3*	1.7 *1.8*	4.3 *4.3*
Stryker 180 N	17.4 *2.7*	10.2 *2.2*	13.5 *4.4*
CA4000 180 N	20.2 *5.6*	12.5 *3.2*	16.0 *5.8*
RSA 180 N	14.9 *3.2*	5.4 *1.7*	9.2 *5.4*

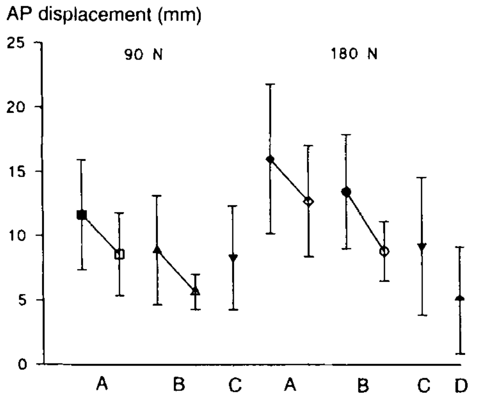

Figure 1. The mean total anterior-posterior displacement in the 11 patients with anterior cruciate ligament lesions where 5 patients were measured prior to and 6 patients one year after a ligament reconstruction. Filled symbols denote injured knees and open non-injured ones. A. CA4000, B. Stryker, C. RSA, and D radiographs.

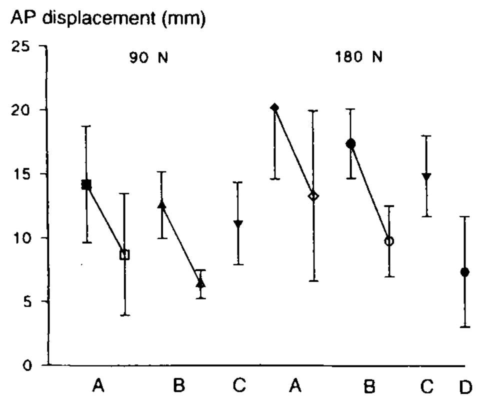

Figure 2. The mean total anterior-posterior displacement in the 5 patients examined prior to a ligament reconstruction. Symbols as in Figure 1.

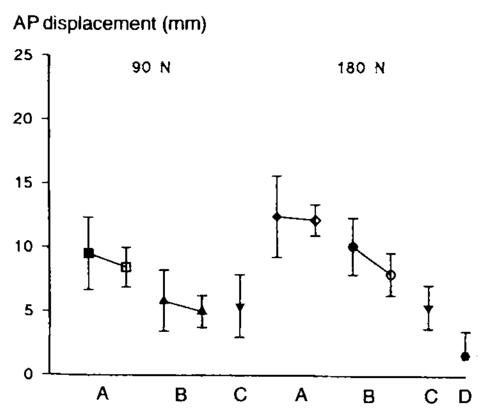

Figure 3. The mean total anterior-posterior displacement in the 6 patients examined one year after a ligament reconstruction. Symbols as in Figure 1.

Discussion

Quantification of anterior-posterior knee laxity is of importance in the treatment of anterior cruciate lesions both in the assessment of the individual patient as well as in the follow-up of different surgical procedures. The variation in reported mean values of measured anterior-posterior tibial displacement with different techniques, both in normal knees and in anterior cruciate ligament-deficient knees (Edixhoven et al. 1989, Steiner et al. 1990) may be attributed to differences in populations and to technical differences in the performance of the instrumented tests. Many of the systemic errors including variations in total laxity of normal knees, can be avoided by analyzing the difference in measured displacement between the injured and non-injured knees (Daniel et al. 1985b). However, efforts must be made to investigate the errors associated with each testing device. Shino et al. (1987) have shown an increased displacement in cadaver knees using an external device when surrounding soft tissues were left intact as compared with the same knee after removal of the soft tissues, except for the ligaments. Also in cadavers, Granberry et al. (1990) have found larger displacements using external devices than by radiographic measurements, despite a computerized compensation for soft tissue compression. Edixhoven et al. (1987) have by simultaneous registrations with RSA and an external device found smaller displacements using RSA, on 2 cadaver specimens. Kärrholm et al. (1988) have found smaller displacements using the RSA technique than those described in the literature when using external devices and suggested this depended on soft tissue compression.

In the *preoperative group* in this study the mean displacement of the injured knees was increased compared with the uninjured, as measured by external devices. No differences were found between these measurements of the injured side between the external devices and RSA.

In the *postoperative group* a larger mean displacement was registered with CA4000 than with Stryker but no difference between the external devices and RSA when a provocative force of 90 N was used. However, when a load of 180 N was used significantly larger displacements were found with the external devices than with RSA. When these measurements were compared with the uninjured knees of the same patients using the same external devices, no difference in measured displacement was found. Thus, the knees were stable and a plausible explanation for the difference in mean values between the external devices and RSA is the deformation of soft tissues around the knee which adds to the skeletal displacement and increases with increased load. The difference CA4000

180 N versus RSA was 7 mm and Stryker 180 N versus RSA 5 mm, which is of the same magnitude as in the in vitro study by Shino et al. (1987).

In the preoperative group no differences were found between RSA and the external devices, which could be explained by the larger anterior-posterior displacements, where the error of soft tissue deformation adds proportionally less to the skeletal displacement.

Other possible errors, such as limb fixation, knee flexion angle (Markolf et al. 1978, Fukubayashi et al. 1982, Emery et al. 1989), position of rotation (Markolf et al. 1984), grade of constrained rotation (Torzilli et al. 1981, Daniel et al. 1985a), point and direction of applied force (Levén 1977, Andersson and Gillquist 1990) or grade of muscle relaxation (Dahlstedt and Dalén 1989) did not differ between the passive measurements. The total anterior-posterior displacements were analyzed to overcome the influence of differences in starting position sagittally (Edixhoven et al. 1989, Kärrholm et al. 1988), and day-to-day variations (Edixhoven et al. 1987, Wroble et al. 1990a,b) were avoided by performing all tests on the same day.

The CA 4000 and Stryker laxity tester used a momentarily applied load of 90 and 180 N repeated 3 times and the mean values were used in the comparative analysis. This means that there might be a component of the anterior-posterior displacement depending on stress/relaxation of the posterior as well as the anterior restraints. The RSA method used a static load of 40 N posteriorly, 90 and 180 N anteriorly during 20–30 seconds which in the same way might add some laxity from stress/relaxation. The difference in posterior load between RSA and the external devices also means that there might be a difference in registered displacement due to the load/displacement curve. In a comparison between a static posterior load of 40 N to a momentarily applied load of 90 N during RSA measurements, the added displacement was insignificant, implying that a static load of 40 N, in addition to gravity, is sufficient for determination of the posterior reference point (Fridén et al. 1992a); we therefore do not believe this difference in loading has influenced the results.

Thus, a considerable proportion of the measured anterior-posterior displacement using external devices was not registered with the RSA technique, which supports the findings by Granberry et al. (1990) and Shino et al. (1987) of an error from soft tissue deformation that adds to the skeletal displacement.

There is, however, a good reproducibility of the measurements with these external devices because the added effect from the soft tissues is constant in the individual patient and when the displacement difference between injured and uninjured knee is used this error can be avoided (Daniel et al. 1985b, Wroble et al. 1990a,b).

When one wants to measure only the skeletal anterior-posterior displacement, the RSA method seems to be superior, but is too time-consuming and complicated for routine use.

It has been suggested that the displacement as measured by weight-bearing radiographs depends on both the degree of laxity and the neuromuscular function of the limb (Fridén et al. 1992b). The weight-bearing method in this study showed a significant positive correlation with the passive measurements in the total group with both stable and unstable knees. In the preoperative and postoperative groups of patients there were, however, differences in mean values, and some patients with a substantial displacement during passive loading did not have any or only a slight displacement when weight bearing and thus were able to keep their joint congruent by active stabilizers in the test situation.

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References

Andersson C, Gillquist J. Instrumented testing for evaluation of sagittal knee laxity. Clin Orthop 1990; 256: 178–84.

Dahlstedt L J, Dalén N. Knee laxity in cruciate ligament injury. Value of examination under anesthesia. Acta Orthop Scand 1989; 60 (2): 181–4.

Daniel D M, Malcom L L, Losse G, Stone M L, Sachs R, Burks R. Instrumented measurement of anterior laxity of the knee. J Bone Joint Surg (Am) 1985a; 67 (5): 720–6.

Daniel D M, Stone M L, Sachs R, Malcom L. Instrumented measurement of anterior knee laxity in patients with acute anterior cruciate ligament disruption. Am J Sports Med 1985b; 13 (6): 401–7.

Edixhoven P, Huiskes R, de Graaf R, van Rens T J, Slooff T J. Accuracy and reproducibility of instrumented knee drawer tests. J Orthop Res 1987; 5 (3): 378–87.

Edixhoven P, Huiskes R, de Graaf R. Anteroposterior drawer measurements in the knee using an instrumented test device. Clin Orthop 1989; 247: 232–42.

Egund N, Fridén T, Bellström T, Lindstrand A, Stockerup R. Radiographic assessment of sagittal knee laxity in weight bearing. Submitted 1991.

Emery M, Moffroid M, Boerman J, Fleming B, Howe J, Pope M. Reliability of force/displacement measures in a clinical device designed to measure ligamentous laxity at the knee. J Orthop Sports Physic Ther 1989: 441–7.

Fridén T, Ryd L, Lindstrand A. Roentgen stereophotogrammetric analysis of laxity and graft fixation after reconstruction of the anterior cruciate ligament. Acta Orthop Scand, 1992a; 63 (1): 80–4.

Fridén T, Egund N, Lindstrand A. Radiographic sagittal displacement during weight bearing in chronic anterior cruciate ligament insufficient knees. Am J Sports Med, Accepted 1992b.

Fukubayashi T, Torzilli P A, Sherman M F, Warren R F. An in vitro biomechanical evaluation of anterior posterior motion of the knee. Tibial displacement, rotation, and torque. J Bone Joint Surg (Am) 1982; 64 (2): 258–64.

Granberry W M, Noble P C, Woods G W. Evaluation of an electrogoniometric instrument for measurement of laxity of the knee. J Bone Joint Surg (Am) 1990; 72 (9): 1316–22.

Kärrholm J, Selvik G, Elmqvist L G, Hansson L I, Jonsson H. Three dimensional instability of the anterior cruciate deficient knee. J Bone Joint Surg (Br) 1988; 70 (5): 777–83.

Levén H. Determination of sagittal instability of the knee joint. Acta Radiol (Diagn) (Stockh) 1977; 18 (6): 689–97.

Markolf K L, Graff Radford A, Amstutz H C. In vivo knee stability. A quantitative assessment using an instrumented clinical testing apparatus. J Bone Joint Surg (Am) 1978; 60 (5): 664–74.

Markolf K L, Kochan A, Amstutz H C. Measurement of knee stiffness and laxity in patients with documented absence of the anterior cruciate ligament. J Bone Joint Surg (Am) 1984 Feb; 66 (2): 242–52.

Noyes F R, Grood E S. Diagnosis of knee ligament injuries. In: Crucial Ligaments (Ed. Feagin, J. A.) Churchill Livingstone, New York 1988; 9: 245–85.

Shino K, Inoue M, Horibe S, Nakamura H, Ono K. Measurement of anterior instability of the knee. A new apparatus for clinical testing. J Bone Joint Surg (Br) 1987 Aug; 69 (4): 608–13.

Steiner M E, Brown C, Zarins B, Brownstein B, Koval P S, Stone P. Measurement of anterior posterior displacement of the knee. A comparison of the results with instrumented devices and with clinical examination. J Bone Joint Surg (Am) 1990; 72 (9): 1307–15.

Torg J S, Conrad W, Kalen V. Clinical diagnosis of anterior cruciate ligament instability in the athlete. Am J Sports Med 1976; 4 (2): 84–93.

Torzilli P A, Greenberg R L, Insall J. An in vivo biomechanical evaluation of anterior-posterior motion of the knee. Roentgenographic measurement technique, stress machine, and stable population. J Bone Joint Surg (Am) 1981; 63 (6): 960–8.

Wroble R R, Van Ginkel L A, Grood E S, Noyes F R, Shaffer B L. Repeatability of the KT-1000 arthrometer in a normal population. Am J Sports Med 1990a; 18 (4): 396–9.

Wroble R R, Grood E S, Noyes F R, Schmitt D J. Reproducibility of Genucom knee analysis system testing. Am J Sports Med 1990b; 18 (4): 387–95.