Laxity and graft fixation after reconstruction of the anterior cruciate ligament

A roentgen stereophotogrammetric analysis of 11 patients

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The sagittal laxity of the knee was measured in 11 consecutive patients with chronic anterior cruciate ligament deficiency before and 1 year after ligament reconstruction with a free bone-tendon-bone graft from the patellar tendon (modified Clancy technique).

Tantalum markers were implanted in the femur, in the tibia, and in the graft for roentgen stereophotogrammetric analysis (RSA) of the sagittal laxity and the migration of the bony ends of the graft. The precision in measurements of total anterior-posterior displacement (± 2 SD of the differences between repeated measurements) was 2.2 mm. A decrease in total anterior-posterior displacement from 12 mm before reconstruction to 5 mm 1 year postoperatively using a stress load of 150 N was found. The bony ends of the free graft migrated maximally 0.7 mm, implying adequate fixation.

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Shino et al. (1987) have, in vitro, found that soft-tissue deformation between the bone and an external measuring device increased the recorded laxity significantly compared with the measured skeletal displacement when all the soft tissues were removed. This error can be avoided by relating measurements of the injured knee to the uninjured side in the individual patient or by using a radiographic method. By using implanted tantalum balls, exact landmarks for measurements can be obtained. Roentgen stereophotogrammetric analysis (RSA; Selvik 1974) applied to the knee has a technical accuracy of 0.2 mm (Ryd 1986), whereas the accuracy in passive dynamic provocations of laxity has been reported to be between 0.8 and 2.0 mm (Kärrholm et al. 1988, 1989). One problem after anterior cruciate ligament reconstructions is to differentiate between slipping of the attachments and elongation or rupture of the graft if there is a recurrent laxity postoperatively. To our knowledge, no previously described method has been able to distinguish between these two reasons.

We have studied the sagittal laxity before and after an anterior cruciate ligament reconstruction and have determined the reproducibility of the method. We have also analyzed movements between tantalum markers inserted into the bony ends of the graft and implanted markers in the surrounding condyle.

Patients and methods

Eleven consecutive patients with chronic anterior cruciate ligament lesions and functional instability despite neuromuscular rehabilitation were studied before and 1 year after an anterior cruciate ligament reconstruction. There were 3 women and 8 men with a mean age at surgery of 28 (17–38) years. The mean time from injury was 40 (8–144) months. Preoperatively, all the patients had a positive Lachman test and a clearly positive pivot shift. Their activity level before injury ranged from occasional recreational sports to competitive contact sports; but all the patients had, because of their injury, reduced their performance level.

The reconstructions were performed using the central third of the patellar tendon as a free graft, including bone blocks from both the patella and the tibial tuberosity. The operations were made through a small anteromedial arthrotomy with a fully controlled notch plasty. The drill guide developed by Odensten and Gillquist (1986) was used to drill trial tunnels in both the tibia and the lateral femoral condyle on a straight line in one sequence with the knee in 90° of flexion. A trial ligament was used to check for impingement in the full range of motion. Measurements of isometry and tension were made using a dynamometer, and the trial tunnels were redrilled if not properly placed. The preload of the graft was 15 N at fixation. The size of the bony ends was controlled by a template to fit the

Figure 1. Tantalum markers in the femur and the tibia. Arrows indicate markers in the bone blocks of the bone-tendon-bone graft.

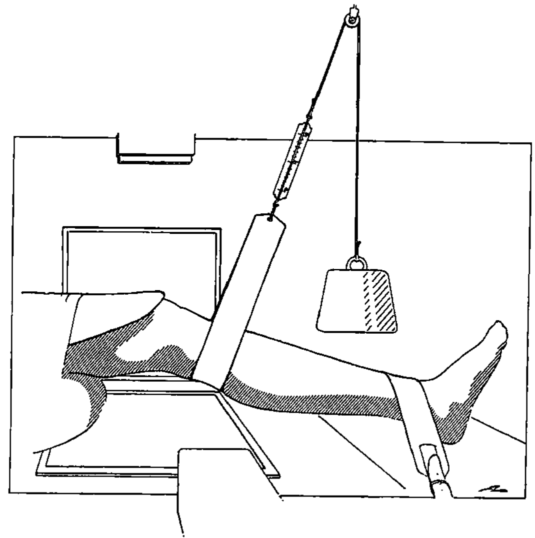

Figure 2. The patient was lying comfortably during application of the different forces. Rotation was not constrained, and measurements were made on simultaneous radiographs in the frontal and lateral projections using three-dimensional roentgen stereophotogrammetry.

tunnels and the placement adjusted to avoid bony ends inside the joint. Fixation of the graft was made by heavy nonresorbable sutures tied over a steel button on both the femoral and the tibial side. A plaster cast was used for 4 weeks in 45° of flexion, followed by carefully monitored physiotherapy that aimed at full rehabilitation after 8–10 months.

Roentgen stereophotogrammetric analysis (Selvik 1974) was used to measure the total anterior-posterior displacement. Four tantalum markers were implanted in the distal femur and four in the proximal tibia at the time of an arthroscopy 2–3 weeks before reconstruction. At the reconstruction, markers were also implanted in the bony ends on both sides of the graft in 5 patients (Figure 1). Stress examinations were made preoperatively and at the 1-year follow-up examination. Simultaneous calibration radiographs were obtained in the frontal and the lateral projection with the straight knee inside a plexiglass calibration cage. Care was taken to place the leg with the tibia 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° ± 5°, and the thigh was fixed in a brace and strapped to the examination table. The foot was prevented from moving anteriorly with a strap, while rotations were unconstrained (Figure 2). The patients were asked to completely relax. A standardized posterior force of 40 N and anterior forces of 50 N, 100 N, and 150 N, applied perpendicular to the tibia 6–8 cm distal to the femurotibial joint line using a pulley system, were subsequently applied. A posterior load of 40 N is less than previously reported in the literature. Therefore, we compared the displacement during this static load of 40 N with the displacement recorded when the knee was loaded with 90 N momentarily in 8 patients.

The marker images on all the radiographs were digitized using a precision digitizing table (Hasselblad Engineering, precision 10 μm). On both radiographs comprising the first stereo pair in the stress series, three imaginary points lying 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 were at the outermost extreme of each tibial condyle, were also digitized. Using the X-Ray program, the 3-D coordinates of the markers at each stress position were obtained and by a point transfer routine in the RSA system, the imaginary points of the first stereo pair were transferred to all the other stereo pairs in the stress series. Motion of the tibia relative to the femur was obtained by the KINEMA routine based on rigid-body kinematics. The results were expressed in a cardinal axis coordinate system where the X-axis is transverse, Y-axis is vertical, and Z-axis is sagittal and rotated so that the axes were parallel to the tibia in the Lachman position.

Table 1. Measured migration (mm) in the 5 patients with tantalum markers in the bony ends of the free graft during the first year

Case No.	Femur	Tibia
2	0.2	0.7
3	0	0.3
6	0.7	0
7	0	0
8	0.6	0.6

Sagittal laxity was defined as the total anteroposterior translation along the Z-axis of the imaginary mid-eminence point between the position during posterior load and the position achieved by each of the three anteriorly directed forces.

During the immediate postoperative period, stereo radiographs were obtained in the supine position to establish the position of the markers in the bony ends of the graft with reference to the tibia and the femur, respectively. The position of these markers were also determined on the calibration radiographs at the 1-year stress examination, the difference representing the motion of the bony ends of the graft during the first year.

To study reproducibility, the 40 N posterior force and either 100 N or 150 N anterior force were applied once more after the patient had been taken down from the examination table and the RSA equipment dissembled and recalibrated. The two recordings of total anterior-posterior displacement thus obtained on 13 test occasions allowed determination of the precision using the formula

$$SD = \sqrt{\frac{\Delta_1^2 + \Delta_2^2 + \Delta_3^2 ... + \Delta_n^2}{n}}$$

Results

From the repeated measurements, the precision of the RSA set-up was determined to ± 2.2 mm (± 2 SD) in the dynamic provocations of total anterior-posterior displacement. The coefficient of correlation between test and retest was 0.93. Before reconstruction, the mean total anterior-posterior displacements (SD) were 5.9 (3.2), 9.5 (3.5), and 11.6 (4.3) mm at a 50 N, 100 N, and 150 N force, respectively. The corresponding values 1 year postoperatively were 4.5 (3.9), 4.3 (3.1, and 4.9 (3.8) mm (Figure 3).

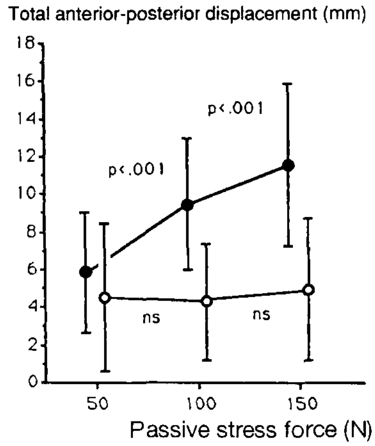

Figure 3. Mean ± SD values of the total anterior-posterior displacement (mm) during different passive stress forces (N) before (●), and 1 year after (○) reconstruction of the anterior cruciate ligament.

Migration of the bone blocks in the tunnels were found in six of the 10 locations during the healing period; however, in no case was the migration more than 0.7 mm (Table 1). To evaluate the posterior reference position, a momentarily applied posterior load of 90 N was compared with the static load of 40 N in 8 patients. Two patients had a paradoxical anterior displacement during 90 N of 8.3 and 2.9 mm, respectively; and the mean difference in the 8 patients was 0.8 (–8.3–1.6) mm less displacement during the momentarily applied 90 N load.

Discussion

Both in the intact knee and after an anterior cruciate ligament rupture, the sagittal laxity is greatest at 20°–30° of flexion (Markolf et al. 1978, 1984, Fukubayashi et al. 1982, Noyes and Grood 1988, Emery et al. 1989), but several errors affect measurements of this laxity.

The unloaded resting position in one specific knee varies (Torzilli et al. 1981, Edixhoven et al. 1987, Kärrholm et al. 1988) after repositioning in a testing device, which means that the total anterior-posterior displacement must be measured, or only an unknown fraction of the total laxity will be recorded (Edixhoven et al. 1987). The degree of muscle relaxation can affect measurements (Markolf et al. 1978), and lumbar anesthesia has been shown to give an increased laxity (Daniel et al. 1985, Dahlstedt and Dalén 1989). To minimize this error, the patients must be comfortable, without pain and too tight strappings during the test. The recordings of less posterior displacement when a higher posterior force was applied in 2 patients are paradoxical, but the same findings have also been reported in the study by King and Kumar (1989). We interpret that this can be due to discomfort and reflex muscle activity in some patients; however, the difference in posterior displacement between a static load of 40 N and a momentarily applied load of 90 N was small and insignificant. Therefore, it appears that static loading of the posterior restraints with 40 N in the Lachman position, in addition to gravity, was adequate to establish a posterior reference point when there is an intact posterior cruciate ligament.

Intertester difference using an external device has been explained by poor limb fixation and soft-tissue deformation/interpositioning. Emery et al. (1989) and Shino et al. (1987) have demonstrated that soft-tissue deformation in vitro accounts for a large proportion of the laxity measured by an external device.

The degree of tibial rotation when constrained affects measurements (Markolf et al. 1984); and when the tibia was allowed to rotate freely, an increase in anterior-posterior displacement of 30 percent was noted by Fukubayashi et al. (1982) .

Despite the existence of errors in many previous investigations, the reproducibility of each test situation is not always accounted for. Shino et al. (1987), using an external device in 49 patients, found differences in mean values of repeated measurements of anterior displacement of 1.2 and 0.4 mm in the injured and the noninjured knee, respectively. When comparing different external device, there were differences in numerical results, but an acceptable repeatability for each device and a positive correlation between the devices in noninjured knees (Highgenboten et al. 1989).

Large interobserver and intraobserver variations have been found when using an external laxity tester in a general orthopedic clinic (King and Kumar 1989), whereas the same device used by experienced examiners had a better repeatability (Highgenboten et al. 1989, Andersson and Gillquist 1990). Day-to-day differences in individual patients have been found by Wroble et al. (1990a and b), and they have calculated a 90 percent confidence limit representing the range around a single measurement, within which the patients true measurement will fall 90 percent of the time. The confidence limits thus obtained with KT 1000 and Genucom when measuring the total anterior-posterior displacement in 25°–30° of flexion were ± 1.5 and ± 3.4 mm, respectively, in noninjured knees using ± 89 N (KT-1000) and 90 N (Genucom), respectively. Radiographically, differences of 2 mm (Levén 1977, Hooper 1986) to 2.4 mm (Jacobsen 1981) have been given between repeated tests. Kärrholm et al. (1988, 1989) have used the RSA technique with a technical accuracy of 0.2 mm, and have reported an accuracy of 2.0 mm in an in vivo test of the total anterior-posterior displacement when associated rotational forces were applied. When the pure sagittal displacement was measured in test-retest of 14 patients, the SD of the difference using a central measuring point was 0.8 mm.

In the present investigation, we have tried to minimize the errors by having an unconstrained rotation of the tibia during the stress test, and measurements were made of the total anterior-posterior displacement. Our patients were placed in a comfortable supine position with the knee in 25° ± 5° of flexion and the load was applied for 20–30 seconds at each testing position. The error from soft-tissue deformation between the bone and an external device can be overcome by using radiographic techniques; and RSA, with implanted intraosseous markers also in the graft, adds the possibility to study the fixation of the graft in addition to the laxity.

The conclusions drawn from this study are that the method had an acceptable reproducibility with a precision of 2.2 mm between repeated tests. In the present patient group, where the central third of the patellar tendon including bone blocks from the patella and the tibial tuberosity was used as a free graft, the laxity was reduced with a definite end point 1 year after reconstruction. The maximal migration of the bony ends of the graft was 0.7 mm, indicating a sufficient fixation. The major advantage of RSA is the possibility to separate stretching or rupture of the graft from an insufficient osseous fixation of the bony ends and thus providing a possibility to compare different fixation techniques and rehabilitation programs. The disadvantage of the method is that it is time consuming to perform, technically complicated to analyze, and implanted markers are a prerequisite, thereby making it suitable mainly for scientific purposes.

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