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# Lengthening of anterior cruciate ligament graft

## Roentgen stereophotogrammetry of 32 cases 2 years after repair

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32 patients with old anterior cruciate ligament injuries were operated on with patellar tendon-prepatellar tissue-quadriceps tendon graft over the top without and with augmentation (Kennedy-LAD). The anteroposterior (AP) laxity was assessed preoperatively, and at 6, 12, and 24 months after the operation with roentgen stereophotogrammetry. 6 months postoperatively the instability had decreased 5.4 mm in the nonaugmented and 1.9 mm in the augmented group, but not to normal values. During the following 18 months the AP laxity increased and returned to the preoperative level. At 2 years, 28 of the 32 patients were considered good or excellent, according to the Lysholm score. There was a lack of correlation between AP laxity and functional tests.

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Loss of function of the anterior cruciate ligament implies mainly increased anteroposterior (AP) instability, and surgical reconstruction aims to restore normal laxity and kinematics. Objective laxity measurement is therefore an important part of the postoperative stability evaluation. Some authors have reported a correlation between good function and reduced AP instability (Lysholm and Gillquist 1982, Johnson et al. 1984), whereas others have not found this correlation (Harter et al. 1988, Seto et al. 1988, Markolf et al. 1989, Barrett 1991).

After over-the-top reconstruction of the anterior cruciate ligament, we have compared the AP laxity with function.

## Patients and methods

Between 1984 and 1988 36 consecutive patients with old tears of the anterior cruciate ligament were operated on using over-the-top technique. One surgeon (LGE) performed all the reconstructions. 3 patients not having a complete preoperative evaluation, and 1 operated with a synthetic graft different from LAD, were excluded from the study. The mean age of the remaining 32 patients (29 men, 3 women) was 26 (18–46) years, and the time between injury and index surgery was 3 years (8 months to 15 years). 21 patients had had other injuries to the knee joint (Table 1); some cases being treated surgically.

### *Surgical techniques*

All reconstructions were performed using a graft made of a central strip of the quadriceps and patellar tendons connected by the prepatellar tissue according to Marshall et al. (1979). The first consecutive 19 patients had no augmentation (the NA group). The following 13 patients (the A group) had their grafts augmented with a polypropylene braid graft (Kennedy-LAD) (Kennedy et al. 1980, Roth et al. 1985).

Table 1. Associated knee injuries and surgery at time of or performed after the anterior cruciate ligament reconstruction

| | Nonaugmented | Augmented |
|---|---|---|
| *Associated knee injuries* | | |
| Meniscus | | |
| Medial | 8 | 4 |
| Lateral | 4 | 3 |
| Collateral Ligament | | |
| Medial | 2 | |
| *Associated surgery* | | |
| Meniscus | | |
| Partial ectomy | | |
| Medial | 1 | |
| Lateral | 1 | 1 |
| Suture | | |
| Medial | 1 | 1 |
| Pes anserinus transposition | 15 | |
| *Subsequent surgery* | | |
| Loosening of adherences | 1 | |
| Drilling osteochondritis | 1 | |
| Tractus iliotibialis plasty | | 1 |
| Diagnostic arthroscopy | | 1 |

Table 2. Rehabilitation program

| Weeks postop | Nonaugmented | Augmented |
|---|---|---|
| | Plaster | Brace (30–60°) |
| >6 | Removable splint (30°–full flexion) | (30°–full flexion) |
| >9 | Brace (30°–full flexion) | |
| >13 | | (15°–full flexion) |
| >14 | Full weightbearing allowed | Full weightbearing allowed |
| >17 | (15°–full flexion) | |
| >26 | | Full range of motion allowed |
| >33 | Full range of motion allowed | |

Restrictions in range of motion are indicated within brackets

The intercondylar area was widened with a notchplasty. A tibial tunnel was drilled, exiting at the old cruciate insertion. The autogenous graft was not detached from its tibial insertion. In the A group the synthetic graft was sutured proximally to the autogenous graft. Both grafts were tensioned and the augmentation was sutured to and wrapped into the autogenous graft in a tubular fashion. The grafts (NA and A) were placed over the top in a bone groove. The knees were flexed to about 30° when the grafts were fixed with one or two barbed staples to the femur. The propylene graft was included in the staple fixation. All but 4 of the patients in the NA group had a complementary pes anserinus transposition at the time of the anterior cruciate ligament reconstruction. Due to increased valgus instability, one of the patients had been operated with a pes anserinus transposition earlier (Table 4, Case 18). In the latter part of the study the pes anserinus transfer was abandoned because it was found not to affect the results (Elmqvist et al. 1988).

The NA group had a cast for 6 weeks, whereas the A group started restricted knee motion immediately (Table 2).

5 patients underwent meniscal surgery at the time of the ligament reconstruction. In 3 patients minor surgical procedures were carried out during the postoperative 2 years (Table 1). Due to recurring episodes of giving way one patient had a tractus iliotibialis plasty (Table 4, Case 32).

### *Roentgen stereophotogrammetry*

At the arthroscopy or during local anesthesia, 3–5 tantalum markers (diameter 0.8 mm) were implanted percutaneously into the distal femur and proximal tibia, bilaterally. The tantalum markers were placed as far from each other as possible, creating 2 polygons.

Examination of the AP displacement was done in the supine position and with the knee in 30° of flexion. AP displacements were measured using 150 N anterior and 80 N posterior tractions (Kärrholm et al. 1988). Preoperatively both the injured and the intact knees were examined. Only the operated knees were examined at the 3 postoperative examinations (6, 12, 24 months). Posterior traction was not performed before the operation in the first 7 patients in this investigation (NA group). The surgical trauma changed the positions of one or two tantalum markers in 3 patients, making comparison between the pre- and postoperative unloaded positions at 30° of flexion impossible, leaving 29 patients for this evaluation.

The reproducibility of the anterior and antero-posterior translations has earlier been calculated at 1.0 and 0.8 mm, respectively (one standard deviation, Kärrholm et al. 1988).

### *Clinical examinations*

The Lachman test and anterior drawer sign were graded 1+ to 3+ (< 5mm, 5–10 mm, > 10 mm) and the pivot shift as absent or present. Examinations were performed without anesthesia. The Lysholm functional score and Tegner activity scale were assessed (Lysholm and Gillquist 1982, Tegner and Lysholm 1985). The first 11 patients (NA) were preoperatively evaluated according to the old Lysholm score (Lysholm and Gillquist 1982), and thereafter according to the modified score (Tegner and Lysholm 1985); these scores are closely correlated (Tegner 1985). One examiner performed all preoperative clinical evaluations (LGE) and another the follow-up examinations (HJ).

The peak torque of the quadriceps muscle at angular velocities of 30°, 90° and 180° was measured with a Cybex II dynamometer (Lumex Inc, N.Y.). The relative values injured/normal knees are presented.

A figure-of-eight track and one-leg-hop tests were used (Tegner et al. 1986a). Hop quotients (injured/normal knee) and turn times in the track are presented. Reference values have earlier been estimated in 30 healthy individuals (Elmqvist et al. 1988).

### *Statistics*

Quantitative continuous variables in the total material were analyzed with the paired Student's *t*-test and Pearson's coefficient of correlation. For submaterials and qualitative variables the sign test, Spearman's rank correlation coefficient and Mc Nemar's test were used.

Table 3. AP translations (mm). Mean *SD*

| Group | n | Preoperative Normal | Preoperative Injured | Preoperative *P*-value[a] | Postoperative 6 Months | $P^b$ | Postoperative 12 Months | $P^b$ | Postoperative 24 Months | $P^b$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Nonaugmented | 12 | 4.6 *1.4* | 12.4 *3.4* | *** | 6.9 *2.9* | * | 7.9 *2.2* | ** | 9.0 *2.0* | n.s. |
| Augmented | 13 | 3.6 *2.1* | 11.4 *3.6* | *** | 9.5 *3.0* | ** | 9.9 *2.3* | n.s. | 10.4 *1.9* | n.s. |

[a]P-values in relation to normal knee. [b]P-values in relation to injured knee. $^*P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

## Results

### *Roentgen stereophotogrammetry*

6 months after surgery the tibial intercondylar eminence, in the nonaugmented group, was placed 1.8 mm (SD 2.7 mm, $P < 0.01$) more posteriorly than at the corresponding preoperative examination at 30° of flexion. At 2 years the tibia had returned to the preoperative position. In the augmented group no change in tibial position was observed 6 months after surgery or later. There was no difference in the degree of flexion between the pre- and postoperative RSA examinations at 6 and 24 months.

The anterior translation in the NA group was reduced by 5.2 mm at 6 months after the operation. No increase in anterior translation could be observed up to 2 years. 2 years postoperatively the translation in the operated knee was 3.8 mm less than preoperatively. In the A group there was no reduction of the anterior translation postoperatively. The posterior translation did not differ between the injured and normal knees and was not influenced by surgery.

6 months postoperatively the operation had reduced the AP translation in the NA group (Tables 3 and 4) by 5.4 mm, but it was still 2.4 mm larger than in the intact knees. During the following 18 months the translation increased by 2.1 mm so that the reduction in AP translation had disappeared. In 9 of the 19 patients the displacement increased more than 1.6 mm between 6 months and 2 years. The A group had a decrease in translation at 6 months but not at the 1- or 2-year follow-up. In 6 of the 13 patients the displacement increased more than 1.6 mm between 6 and 24 months.

### *Functional*

Preoperatively all but 2 patients had a positive pivot shift. At the 2-year follow-up pivot shift could be demonstrated only in one of the patients. The patient reoperated with the tractus iliotibialis transfer had a positive pivot shift prior to the reoperation but not at the 2-year follow-up. The anterior drawer and Lachman tests indicated decreased anterior tibial displacement in both groups (Table 5). The functional score and the activity level improved. 28/32 were good or excellent.

Table 4. Anteroposterior laxity in 32 cases of anterior-cruciate-ligament reconstructions. Figures within brackets for the 7 first cases represent only anterior traction

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| 1 | 2 | | | 5.6 | 8.6 | 7.3 |
| | | (6.8) | (15) | (5.2) | (8.0) | (7.3) |
| 2 | 2 | | | 7.3 | 5.0 | 8.0 |
| | | (1.5) | (10) | (2.8) | (4.8) | (4.9) |
| 3 | 2 | | | 9.3 | 9.2 | 9.7 |
| | | (1.5) | (11) | (7.2) | (7.2) | (8.0) |
| 4 | 2 | | | 4.3 | 6.5 | 9.5 |
| | | (2.7) | (7.0) | (3.8) | (5.6) | (8.8) |
| 5 | 2 | | | 8.3 | 9.5 | 8.4 |
| | | (5.6) | (9.8) | (6.9) | (8.7) | (7.3) |
| 6 | 2 | | | 8.6 | 2.9 | 11 |
| | | (3.5) | (6.6) | (8.0) | (2.9) | (11) |
| 7 | 2 | | | 3.3 | 6.6 | 4.6 |
| | | (6.4) | (11) | (3.3) | (3.4) | (0.0) |
| 8 | 2 | 6.6 | 14 | 8.0 | 7.7 | 6.4 |
| 9 | 3 | 1.5 | 17 | 13 | 12 | 13 |
| 10 | 1 | 3.9 | 18 | 10 | 12 | 11 |
| 11 | 2 | 5.8 | 10 | 7.0 | 8.1 | 9.9 |
| 12 | 2 | 5.5 | 16 | 6.8 | 7.6 | 10 |
| 13 | 2 | 4.6 | 11 | 12 | 10 | 13 |
| 14 | 2 | 4.0 | 13 | 4.7 | 7.8 | 7.5 |
| 15 | 2 | 6.7 | 18 | 10 | 10 | 10 |
| 16 | 2 | 4.4 | 12 | 5.0 | 5.4 | 8.7 |
| 17 | 2 | 2.5 | 10 | 0.2 | 6.0 | 8.4 |
| 18 | 1 | 2.5 | 8.1 | 9.6 | 10 | 11 |
| 19 | 1 | 4.2 | 10 | 5.6 | 8.9 | 10 |
| 20 | 3 | 3.4 | 16 | 8.5 | 11 | 11 |
| 21 | 3 | 7.4 | 13 | 12 | 13 | 14 |
| 22 | 3 | 2.4 | 7.8 | 7.8 | 8.4 | 9.8 |
| 23 | 3 | 2.6 | 6.9 | 6.1 | 6.3 | 7.4 |
| 24 | 3 | 4.3 | 14 | 12 | 10 | 9.4 |
| 25 | 1 | 4.3 | 8.7 | 5.3 | 6.6 | 6.2 |
| 26 | 3 | 7.9 | 14 | 14 | 13 | 12 |
| 27 | 3 | 2.7 | 7.7 | 5.9 | 8.0 | 10 |
| 28 | 3 | 3.6 | 7.5 | 6.0 | 7.4 | 9.1 |
| 29 | 3 | 2.8 | 15 | 10 | 8.5 | 9.4 |
| 30 | 3 | 4.8 | 11 | 10 | 10 | 9.7 |
| 31 | 3 | 1.9 | 11 | 5.8 | 8.1 | 8.5 |
| 32 | 3 | 1.3 | 7.8 | 11 | 11 | 11 |

A Case
B Type of surgery
  1 Nonaugmented
  2 Nonaugmented + pes anserine transfer
  3 Augmented with LAD

*AP displacement (mm)*
C intact knee
D injured knee
E 6 months postop
F 12 months postop
G 24 months postop

Table 5. Clinical examination and evaluation preoperatively and at the 2-year follow-up

| | | Nonaugmented | | | Augmented | | |
|---|---|---|---|---|---|---|---|
| | | Preop | | 2 years postop | Preop | | 2 years postop |
| Anterior drawer | 1+ | 0 | | 10 | 0 | | 6 |
| | 2+ | 9 | ** | 9 | 5 | * | 7 |
| | 3+ | 10 | | 0 | 8 | | 0 |
| Lachman | 1+ | 0 | | 11 | 0 | | 11 |
| | 2+ | 7 | ** | 8 | 2 | *** | 2 |
| | 3+ | 12 | | 0 | 11 | | 0 |
| Lysholm score | 0–64 | 13 | | 2 | 3 | | 0 |
| | 65–83 | 6 | | 2 | 10 | | 0 |
| | 84–94 | 0 | | 4 | 0 | | 3 |
| | 95–100 | 0 | | 11 | 0 | | 10 |
| Median | | 60 | *** | 95 | 69 | *** | 96 |
| Range | | (45–80) | | (51–100) | (54–76) | | (90–100) |
| Tegner scale | 0–3 | 5 | | 4 | 3 | | 0 |
| | 4–6 | 14 | | 5 | 10 | | 5 |
| | 7–10 | 0 | | 10 | 0 | | 8 |
| Median | | 4 | ** | 7 | 4 | *** | 7 |
| Range | | (0–6) | | (2–9) | (2–6) | | (4–9) |

* $P < 0.05$, ** $P < 0.01$ *** $P < 0.001$

At 2 years the injured knees had between 0.82 and 0.89 of the intact knee strength depending on the angular velocity at the examination. Using a ratio of 0.9 (Tegner et al. 1986b) or more as the goal for the rehabilitation, 16/32 cases reached that level at the fastest and 7/32 at the slowest angular speed. High activity levels (≥ 6) implied greater muscle strength at all 3 angular velocities compared with lower activity levels (0.94 and 0.81; $P <$ 0. 05). Both groups had longer turn times compared with a normal reference group. 15 of the 32 patients had a turntime within 2 standard deviations of the reference population. The mean value of one leg hop quotient was 0.92. Twenty-five of the patients had a ratio within 2 standard deviations of the reference group.

There were no correlation between the translations recorded at the laxity tests (difference injured-normal) and function score, activity level, performance, or muscle strength.

## Discussion

In some patients the same or almost the same displacements were recorded before and 6 months after surgery, indicating insufficient stability at surgery, early graft elongation, or rupture. However, preliminary studies of 7 patients examined under epidural anesthesia the first postoperative day showed substantial reduction of AP displacements followed by increasing values during the rehabilitation period. In some knees, slowly increasing AP translations were recorded after 6 months, suggesting another mechanism. Improper placement or poor anchorage of the graft may result in early failure, whereas decreasing strength due to revitalization may be of importance for later elongation. Augmentation did not seem to protect the graft from eventual elongation.

Autografts undergo necrosis, revascularization, and remodeling. During this time they are weak and at increased risk for elongation or rupture (Alm et al. 1974, Kennedy et al. 1980, Arnoczky et al. 1982, McPherson et al. 1985). In animal studies revascularization is completed within 2–5 months, and thereafter the graft resembles a normal ligament (Alm et al. 1974, Arnoczky et al. 1982). However, probably it never reaches a tensile strength of more than 30–50 percent of the anterior cruciate ligament (McPherson et al. 1985, Newton et al. 1990). Forces generated by temporary decreased graft strength during healing and by increasing activity during the later part of the rehabilitation period may thus cause failure of the graft with increased laxity within the first postoperative years.

The quadriceps-tendon-patellar ligament is one of the weakest grafts used for cruciate reconstruction (Noyes et al. 1984). Augmenting the graft with a polypropylene braid may increase its strength (Kennedy et al. 1980, McPherson et al. 1985), reducing the load on the autograft by one third (Hanley et al. 1989).

Graft competence in the early postoperative period depends on the fixation technique (Kurosaka et al. 1987). Fixation with staples is weaker than different types of screw fixation (Daniel et al. 1987, Kurosaka et al. 1987). Our staples fixation may have loosened by the early mobilization in the augmented group although it was started in a safe range of motion (Markolf et al. 1990). Pull out at the weakest point of the graft at the tibial end is even more likely (McPherson et al. 1985).

The positions of the graft insertions are critical with the femoral insertion being more important than the tibial one (Hefzy et al. 1989, Schutzer et al. 1989). Positioning the graft over the top on the femur results in elongation of the graft during extension (Odensten and Gillquist 1985, Schutzer et al. 1989). In our series a femoral bone groove was used to achieve a position more close to the isometric one (Penner et al. 1988)

Some studies have documented normalization of the sagittal displacement in the majority of the patients after over-the-top reconstruction (Daniel et al. 1988, Dahlstedt et al. 1990, Howe et al. 1991). Different loads and techniques of measurement compared to the RSA set-up (Jonsson et al. 1990) could be one explanation for the discrepancies with our result. When the KT-1000 is used according to the manual the reference position is achieved by pushing the tibia posteriorly several times. The posterior position reached is probably less reproducible and more anteriorly located, compared to the use of a posterior traction as in the RSA evaluation. The importance of inaccuracies in determining the reference position will also increase with the size of the instability. Therefore measurements between the anterior and posterior endpoints are preferable (Wroble et al. 1990).

Clinical examinations of knee stability only evaluate passive knee restraints, whereas functional stability is a more comprehensive entity (Noyes et al. 1980), including also factors such as muscle strength, knee compliance, and proprioception (Barrett 1991). Physiotherapy alone may improve the function (Tegner et al. 1986b). However, our patients had been on a rehabilitation program before the index surgery, and postoperative muscle exercise does not increase the strength further (Elmqvist et al. 1988); only half of our patients reached the projected relative muscle strength, suggesting other reasons for the functional improvement.

The positive effect on knee function in our series may be due to increased knee stiffness (Markolf et al. 1989), improved proprioception and reduction or elimination of pivot shift. The clinical implications of a permanent increase in AP laxity, despite absence of episodes of giving away and positive pivot shift, are unclear. Although one long-term study of the nonaugmented Marshall procedure showed a low frequency of positive pivot shift (Howe et al. 1991), we are concerned about the poor stabilizing effect in our patients and especially in those with the augmented repair with ligament lengthening, despite a fairly conservative rehabilitation program. We have therefore abandoned the Marshall procedure, augmented and nonaugmented, during the evaluation of alternative surgical techniques.

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