No bone ingrowth into the tibia tunnel in anterior cruciate ligament-reconstructed patients

A 1-year prospective quantified CT study of 10 patients reconstructed with an autologous bone-patellar tendon-bone graft

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ABSTRACT – 10 patients with major instability symptoms due to an acute anterior cruciate ligament injury were operated on with a bone-patellar tendon-bone reconstruction. Tibial condyle bone mineral density (BMD), bone ingrowth and changes in diameter in the tibia bone tunnel were studied with quantified computed tomography (QCT) postoperatively and after 1, 3, 6 and 12 months.

We found no sign of bone ingrowth in the form of increased bone mineral density (BMD) in the bone tunnels in any of the patients. The tunnel diameter increased in all patients during the first postoperative months. After 1 year, 5 patients had a smaller diameter than at the first postoperative examination, 2 had the same diameter as immediately after surgery and 2 patients had a larger diameter. A sclerotic zone developed in all patients along the perimeter of the tunnel during the 3–6 months of follow-up. The BMD in the tibial condyle decreased at 3 months; it then increased, but between 6 and 12 months, it levelled out and was slightly lower than postoperatively.

In conclusion, we found no growth of bone into the tunnel and tendinous part of the graft during the first postoperative year.

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Anterior cruciate ligament injuries are reconstructed mainly in young, physically active persons. The intraarticular methods use a drilled bone tunnel in the proximal tibia, through which the transplant is introduced into the knee. Animal studies have shown incorporation of autogenous and synthetic grafts into the bone tunnel with good mechanical strength and also bone growth into the transplant (McPherson et al. 1985, Paavolainen et al. 1993). However, this does not agree with our observations in patients reconstructed with Gore-tex and Kennedy LAD synthetic anterior cruciate ligaments. We have found widening of the tunnel and poor mechanical strength of the graft/bone tunnel interface at revision surgery due to reinjury or synovitis.

One of the commonest techniques today in anterior cruciate ligament reconstruction is the bone-tendon-bone (BTB) technique using a patellar tendon graft with a proximal and distal bone block. In the present study, we use quantified computed tomography (QCT) to evaluate tunnel remodeling/widening and bone ingrowth.

Patients and methods

10 patients (7 men), mean age 26 (20–35) years, with acute (6 weeks or less), arthroscopically-verified anterior cruciate ligament rupture, were included after informed consent. They all had positive pivot shift, positive Lachman test, and high physical demands and we therefore chose to perform an anterior cruciate ligament reconstruction. 3 senior surgeons performed the operations. The local ethics and radiation safety committees approved the study.

Operation technique

Via a ventral incision from the apex of the patella to the tibial tubercle, the central third of the patellar tendon was harvested in full thickness with about 2–2.5 cm long proximal and distal bone blocks. The graft was trimmed and its diameter measured. A drill, with a diameter (8–10 mm) that would just fit the graft, was selected and the tibia tunnel, starting on the medial side and about 4 cm below the tibia plateau, was drilled with a standard drill using a drill-guide. The tunnel was directed towards the tibial insertion of the anterior cruciate ligament. The femoral ligament insertion was positioned with a transtibial femoral drill guide, the femoral cavity (usually 25 mm deep) was prepared with an acorn drill (Figure 3). The graft was pulled into place retrogradely, and fixed in the femoral cavity. After pretensioning and an isometric test, it was fixed in the tibia tunnel under manual tension. The bony ends of the graft were fixed in the tunnels on both the femoral and tibial sides with interference screws. Notchplasty was performed if the notch diameter was less than 16 mm.

Bloodless field, medial miniarthrotomy and preoperative antibiotics were always used.

Rehabilitation

Full weight bearing and full range of motion were allowed immediately; no brace was used. Postoperative weeks 0–2 included transcutaneous electrical muscle stimulation (TEMS) together with isometric quadriceps contractions, one-leg cycling, straight-leg raising and active joint motion training; weeks 3–4 eintailed training in water after the sutures were removed, two-leg cycling, squatting and lying-down hip extension with 90° flexion of the knee. In weeks 5–11, one-leg training was started on the operated knee; squatting, step-ups with increasing weight, and coordination exercises on a balance-board.

Each patient underwent a functional evaluation after 12 weeks including the ability to jog, run in a figure-of-eight, run fast and stop, one-leg jump forward and zigzag, and one-leg squats. Rehabilitation was adjusted according to the results of this test which commenced with light jogging and running exercises, cross-country skiing, isokinetic musclestrength exercises.

After 5–6 months, training in specific sports was allowed and return to full sports activities was usually possible after 10–12 months.

Radiological examination

Quantitative computed tomography (QCT) is a software installed in our CT (GE Pace Plus). By using a calibration phantom as a standard, one can provide absolute measurements of the bone mineral density (BMD), in a chosen region of interest (ROI), given as calcium hydroxyapatite mg/cm^3. We have previously reported the precision and accuracy (Adolphson et al. 1993).

The examination was performed with the operated knee slightly flexed, resting on a custom-made cushion. The other knee was flexed about 90°, to avoid interference in the localization scan (Scout View). From the Scout View, the long axis of the tibia bone tunnel was estimated, the inner limitations of the tunnel were set with the cursor at about 400 Hounsfield units (HU) and the scans were taken in an angle perpendicular to the tunnel. At each examination 5–7 scans were taken, consisting of 5 mm thick slices and 5 mm intervals, between the proximal tip of the distal bone block and the joint level. The patients were examined 5 times: the first postoperative day and again after 1, 3, 6, and 12 months. Each time, the anterior/posterior (A/P) and medial/lateral (M/L) diameters of the bone tunnel were measured in all slices. A circle was placed as the ROI in the center of the tunnel, made as large as possible without touching the bony walls of the tunnel. The BMD was calculated in all slices containing tendon alone. In the proximal tibia, the BMD was calculated after tracing the outline of the entire circumference, including both cortical and cancellous bones in the ROI. These calculations were made from the same slices perpendicular to the bone tunnel, not parallel to the joint level and thus not at an exact level from the joint line. All the measurements on CT were made by the same radiologist (EB).

To validate the method of measuring the tunnel diameter, 2 tunnels with each diameter, 1 using an acorn (8, 9 and 10 mm) and 1 a standard drill (8, 9 and 10 mm) were drilled into 6 different bovine tibias. The specimens were then placed in water, using a steel rod as a marker placed in the tunnel. This was done to ensure exact positioning in the gantry and show the angle of the tunnel on the

Patients' data during follow-up

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
M	10.0	9.8	9.9	10.9	10.9	11.0	10.2	11.1	10.1	10.4	9.9	59	48	59	53	51	N	N	(Y)	Y	Y
F	9.0	9.6	9.0	9.0	9.4	8.6	9.2	8.2	8.0	7.3	8.3	48	49	46	57	48	N	N	(Y)	Y	Y
F	9.0	9.2	9.2	9.5	9.3	8.6	9.4	8.4	9.2	8.0	8.4	52	50	54	62	59	N	N	N	Y	Y
M	9.0	10.4	9.3	11.2	10.1	10.4	9.2	9.6	9.2	9.1	8.9	34	59	42	45	65	N	(Y)	Y	Y	Y
M	9.0	10.4	8.9	10.8	10.3	10.5	10.0	10.2	9.6	9.4	8.6	44	54	45	46	56	N	N	(Y)	Y	Y
M	9.0	10.6	9.4	10.8	10.6	10.0	10.6	9.7	9.4	9.4	9.4	61	60	43	54	40	N	N	Y	Y	Y
F	8.0	9.5	8.6	9.0	8.7	10.4	8.9	10.2	8.1	9.8	8.2	59	43	32	39	40	N	N	Y	Y	Y
M	9.0	10.3	10.4	12.2	10.4	12.1	10.4	/	/	10.6	9.1	47	44	45	/	58	N	N	(Y)	/	Y
M	8.0	7.1	8.0	/	/	8.3	9.6	7.8	8.4	/	/	54	/	48	50	/	N	/	(Y)	Y	/
M	10.0	11.0	10.1	12.0	12.0	11.3	11.4	11.4	11.0	11.7	10.9	48	45	53	38	38	N	N	(Y)	Y	Y

A Gender
B Drill diameter (in mm of drill used)
C Anterior/posterior diameter (mm) postoperatively
D Medial/lateral diameter (mm) postoperatively
E Anterior/posterior diameter (mm) 1 month
F Medial/lateral diameter (mm) 1 month
G Anterior/posterior diameter (mm) 3 months
H Medial/lateral diameter (mm) 3 months
I Anterior/posterior diameter (mm) 6 months
J Medial/lateral diameter (mm) 6 months
K Anterior/posterior diameter (mm) 12 months
L Medial/lateral diameter (mm) 12 months

M–Q. Tibial tunnel bone mineral density (calcium hydroxyapatite mg/cm^3)
M postoperatively
N 1 month
O 3 months
P 6 months
Q 12 months
R–V. Sclerosis in tibial tunnel wall, Y/N (yes/no)
R postoperatively
S 1 month
T 3 months
U 6 months
V 12 month

Scout View. The steel rod was then removed. The scans were made perpendicular to the long axis of the bone tunnel and also at 10° and 20° angles, with 5 mm thick slices and at 5 mm intervals. 10–15 slices were made in each specimen.

On each slice of bovine bone, the A/P and M/L diameters were measured, using the same method as with the patients. After the radiological examinations, the tunnels were filled under pressure with polymethylacrylate (Palacose) bone cement. The bone was extracted after curing and the casts of the A/P and M/L diameters were measured at 5 mm intervals, using an electronic digital caliper (measurement exactness 0.003 mm).

Statistics

The Student's t-test was used for the CT diameter and BMD measurements. We calculated the mean values with the two methods to compare the casts and CT examinations.

Results

We found no sign of bone ingrowth in the form of increased BMD in the tendinous part of the graft in any of the patients. Both the A/P and M/L diameters had increased in all patients at 1 month (A/P: $p = 0.09$, M/L: $p = 0.009$). On the last examination after 1 year, 5 patients had a smaller diameter than at the first postoperative examination, 2 the same as at the first one, 2 a larger diameter and 1 could not be contacted for the final examination (Table). This change in diameter between 1 and 12 months was significant (A/P: $p = 0.007$, M/L: $p = 0.0001$), but there were no significant differences in diameters between postoperative measurements and those at 12 months (Figure 1).

At the time when the diameters started to decrease below the measurements made postoperatively, a sclerotic zone could be seen at the perimeter of the tunnel in all patients. This zone became more marked during follow-up (Figure 4).

In the first postoperative month a small decrease occurred in the tibial condyle's BMD in 7 patients, which was more maked in 2 patients. The BMD then stabilized and increased slowly but did not return to the initial values (Figure 2).

The mean difference between measurements of the CT scans and the casts made from the bovine tibia tunnels, drilled with standard drills, was 0.2 mm (0.0—0.4). When measuring tunnels drilled

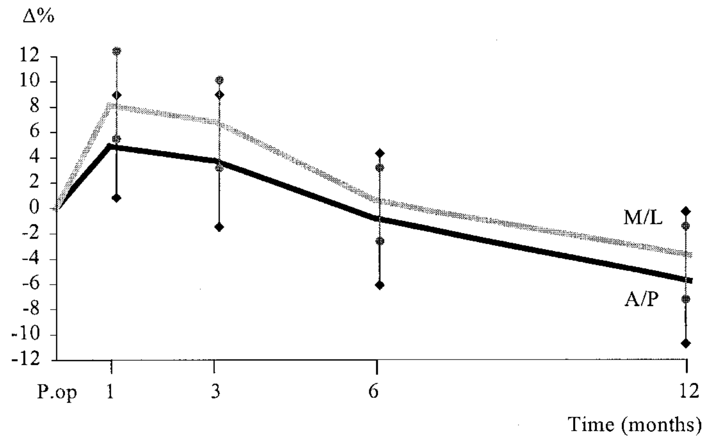

Figure 1. Mean changes (in percent) in anterior/posterior (A/P) and medial/lateral (M/L) diameters during follow-up.

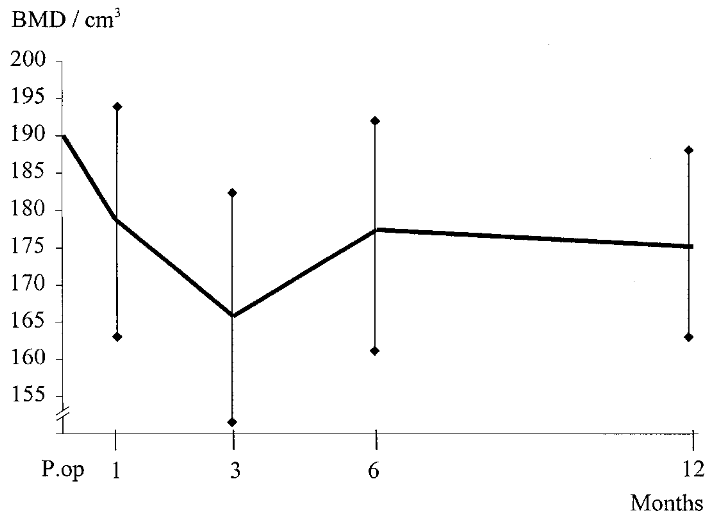

Figure 2. Changes in tibial condyle BMD during follow-up (in mean mg of calcium hydroxyapatite/cm^3).

with acorn drillbits, we found a difference of 0.6 mm (0.1–1.6), with the cast always larger than the CT measurements. In the tunnels drilled with acorn drills, we found a zone with high attenuation at the perimeter of the tunnels. This was not seen in tunnels made with standard drills. When the measurements were made at 20° angles against the long axis of the tunnel, the A/P measurements increased by 6%.

The acorn drill produced a smaller diameter than the standard one on the CT and casts—i.e., CT –0.1 mm vs. –3.7 mm, resectively, and casts –0.3 mm vs. –3.0 mm, resectively.

Discussion

Various anterior cruciate ligament grafts have been shown to become incorporated with growth of bone into the bone tunnel. However, most studies (Mäkisalo et al. 1988, Rodeo et al. 1993) have been done on animals (dog, pig, sheep and rabbit).

Through mechanical cadaver studies and histological examination of dogs operated on with the BTB-technique, the graft has been seen to be securely fixated in the bone tunnel 0–4 months after surgery (Chiroff 1975, Kurosaka et al. 1987. Nagano et al. 1997). Our aim was to determine in humans whether bone ingrowth occurs in the tendon portion of the graft along its course through the bone tunnel. If not, there is a risk that the

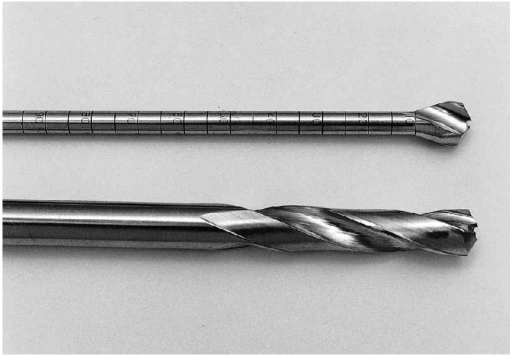

Figure 3. Drillbits used. Acorn (upper) and standard (lower) drills.

tendon part of the graft will wear at the tunnel wall and thereby widen the tunnel or break itself, with an increased risk of late failure.

Arnoczky et al. (1988) found marked bone ingrowth into Gore Tex and knitted Dacron prosthesis in a bone tunnel in dogs 6 months after implantation. The ingrowth was shown on high-resolution radiographs. In a study on sheep (Paavolainen et al. 1993) 12 months after implantation of a Gore Tex ligament, histological examination showed trabecular bone growth into the prosthesis. Both studies reported that mechanical fixation strength was related to bone growth into the prosthesis. In our study of BTB-grafts, we found no signs of bone growth into the tendon part of the graft, but the bone tunnel had narrowed during the follow-up. If bone growth had taken place in the tendon to the same extent as in the two studies mentioned, the BMD would have increased in the center of the tunnel.

Mäkisalo et al. (1988) reported that all carbon fiber prostheses enveloped in fascia lata failed mechanical tests by pulling out the prosthesis of the fascia lata. They found maturing scar tissue in the bone tunnel between the viable fascia and the bone. Rodeo et al. (1993) transplanted the proximal part of the long digital tendon into a bone tunnel in the tibia metaphysis of dog. In this way the incorporation of the graft was studied under a physiological load. Histological examination showed gradual increase of collagen fibre continuity between the tendon and bone, with maturation of fibers which became aligned along the load axis and were morphologically identical with Sharpey’s fibers that are found at ligament insertions into periost and anchor intravertebral discs to the vertebrae. Radiographs showed new woven bone, seen as sclerosis, along the bone tunnel. It was thicker and more collagen fiber continuity was present at sites of greater bone/tendon contact stress. The mechanical strength of the tendon in the bone tunnel was correlated with the increasing mineralization and maturation of healing tissue. Similar findings have been reorted by Grana et al. (1994) in a study of tendon healing in a bone tunnel on 14 rabbits with a follow-up of 2 –12 weeks. Tendon fixation

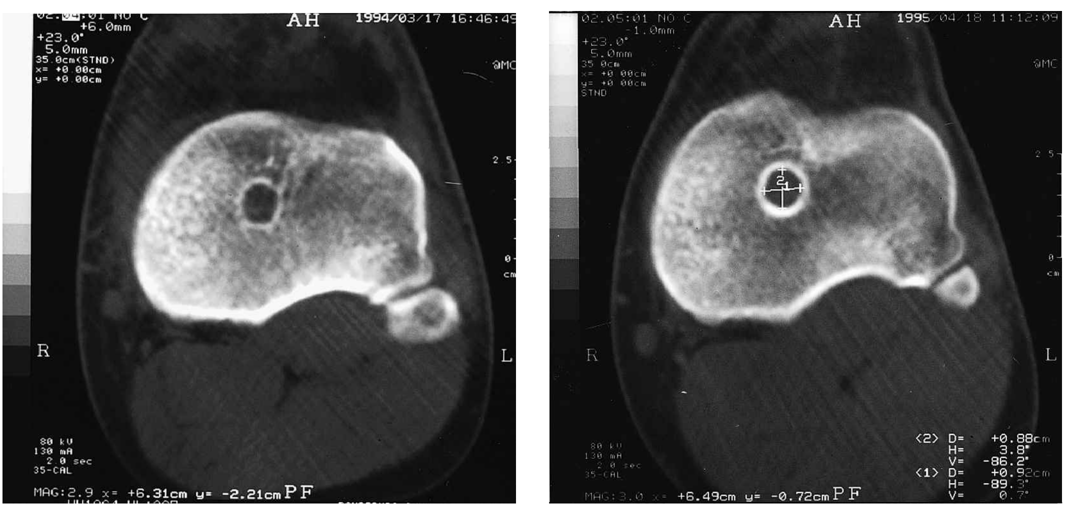

Figure 4. CT examinations in a given patient immediately after surgery (left) and again 13 months later (right). Note the dense, high attenuating zone lining the bone tunnel at 13 months.

occurred in the tunnel with connective tissue in the form of Sharpey fibers between the graft and bone. Bone also formed in the perimeter of the tunnel. The connective tissue and bone increased with time as also did the mechanical fixation of the graft in the tunnel.

The radiological findings of the studies abovementioned are in accordance with ours. We found an increase in sclerotic bone formation along the tunnel, most marked dorsally in the tunnel at the entrance of the joint. This is where the contact stress is greatest when the ligament is under tension in the anterior drawer (i.e., physiological loading).

The accuracy of bone tunnel diameter measurements was acceptable, but the kind of drill used affected the results. The acorn drillbit produced a smaller and more irregular CT scan diameter, with a high attenuating zone of impacted bone at the perimeter of the tunnels. More studies are needed to determine whether use of an acorn drillbit also affects the bony incorporation of the graft in the tunnel.

Tibial condyle BMD measurements indicate that although the patients were rehabilitated according to a modern protocol, they showed the same amount of bone mineral loss as those with inactivity/posttraumatic osteopenia (Nilsson 1966, Ahl et al. 1988). It seems likely that they did not put full weight on their operated leg because of pain, which therefore induced an inactivity osteopenia. Ahl et al. (1988) found no difference in postoperative bone mineral content between fracture patients who were allowed immediate weight bearing and those who were not allowed to do so for the first 4–5 postoperative weeks. In our study, at the 6-week follow-up, all the patients were walking without crutches and with full weight on the operated leg.

In an anterior cruciate ligament reconstruction using autologous tendon grafts, our findings indicate that the graft is not incorporated into the bone tunnel by bone growth into its tendonous part of the graft.

New devices to fixate cruciate ligament grafts in the bone tunnel, said to enhance bone formation and thereby incorporation of the graft, are now becoming available. Biodegradable cruciate ligament substitutes, which act as scaffolds to endogenous cells are also being developed. We feel that our method of studying the bone tunnel part of these reconstructions will be of value.

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