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Bone tunnel enlargement after anterior cruciate ligament reconstruction with the hamstring autograft and endobutton fixation technique

A clinical, radiographic and magnetic resonance imaging study with 2 years follow-up

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Abstract The aim of this study was to describe the contrast-enhanced magnetic resonance imaging (MRI) appearance of bone tunnel enlargement detected on radiography after anterior cruciate ligament (ACL) reconstruction with semitendinosus and gracilis tendon endobutton (STG-endobutton) fixation technique. Fourteen patients with a STG-endobutton ACL reconstruction were examined 3 months ($n = 1$), 1 year ($n = 1$) and 2 years ($n = 12$) postoperatively. An age- and sex-matched group with a bone–patellar tendon–bone (BTB) autograft ACL reconstruction with similar follow-up was taken as control. Data on clinical examination, laxity and isokinetic muscle torque measurements, anteroposterior and lateral view radiography were obtained, and knee scores (Lysholm and Tegner) were collected. Contrast-enhanced MRI was performed in the STG-endobutton group with a 1.5-T imager. There were no statistical differences between the groups with respect to clinical findings, stability tests, or knee scores. In the STG-endobutton group the average femoral and tibial bone tunnel diameter detected on anteroposterior view radiography had increased at 2-year follow-up by 33% and 23%, respectively. On MRI the ligamentous graft itself was not enhanced by the contrast medium whereas periligamentous tissue within and around the STG graft bundles showed mild contrast enhancement. In conclusion, the MRI results suggest that enhancing periligamentous tissue accumulated in and around the STG graft associated with the tunnel expansion. In spite of the significant bone tunnel enlargement observed on the follow-up radiography the STG-endobutton knees were stable and the patients satisfied.

Key words Anterior cruciate ligament reconstruction · Bone tunnel enlargement · Hamstring tendons · Magnetic resonance imaging · Radiographic evaluation

Introduction

Bone–patellar tendon–bone (BTB) reconstruction technique is the most commonly used method in anterior cruciate ligament (ACL) reconstruction [3]. Due to sometimes annoying patellofemoral problems and anterior knee pain an otherwise successful operation may remain unsatisfactory [21]. An alternative technique is to use the semitendinosus and gracilis (STG) tendons to avoid interfering with the extensor mechanism; however, in this case fixation of the graft is a problem. A fixation option is the "endobutton" technique presented by Rosenberg [18]. There are only a few follow-up reports of this technique [12, 13]. In our experience, there has been no reason for concern in terms of stability, but a constant finding on radiography at 2-year follow-up is a widening of the bone tunnels to a far greater extent than after BTB reconstruction. Magnetic resonance imaging (MRI) after ACL reconstruction has been used in few studies to evaluate the postoperative findings in the knee joint [17, 23, 24]; however, very little is known of MRI in evaluation of STG autograft appearance [8, 11]. To our knowledge, no studies have been published on MRI evaluation of bone tunnel enlargement.

This study analyzed the phenomenon of bone tunnel enlargement with radiographic and contrast-enhanced MRI after ACL reconstruction with STG autograft and the endobutton fixation technique.

Materials and methods

Our prospective series included 105 patients with chronic anterior knee instability who underwent arthroscopic ACL reconstruction. To compare various reconstruction methods the patients were randomized by their birth year into STG-endobutton and BTB groups. There were no bilateral ACL reconstructions in this randomized material. In the STG-endobutton group the surgical procedure was performed arthroscopically with double-loop STG. The proximal fixation was carried out by the endobutton method [2, 19] and the distal fixation with an AO screw and spiked washer post. The size of the drill channels was as close as possible to the diameter of the graft. In the BTB group the surgical procedure was an “outside-in” arthroscopic assisted technique using the central third of the patellar tendon as a free autograft with matching drill channels and interference screw fixation. No braces were used in the postoperative rehabilitation, and all knees were immediately mobilized with full weight bearing 2 weeks postoperatively. Return to sports activities was allowed gradually, usually without limitations 6–12 months postoperatively.

Clinical evaluation of knee function and stability was performed preoperatively and 1 and 2 years postoperatively. Objective anteroposterior (AP) knee stability was determined using an arthrometer (CA 4000, OSI, Hayward, Calif., USA), and isokinetic muscle torque of flexor-extensor system of the knee joint was measured (Lido, Multi-Joint II, West Sacramento, Calif., USA). The Lysholm knee score, Tegner activity level, and International Knee Documentation Committee forms were filled in [6].

From the original randomization protocol contrast-enhanced MRI was performed on 14 consecutive patients in the STG-endobutton group (ten men, four women, median age 35 years). Selection criteria for this study was patient willingness to participate on MRI after their routine clinical examinations 3 months ($n = 1$), 1 year ($n = 1$), and 2 years ($n = 12$) postoperatively. From the BTB group of our original randomization protocol, 14 patients matched by age, sex, and follow-up time were selected as controls for clinical evaluation. In the STG-endobutton group there was one patient with a revision ACL surgery and one with primary suturing of the torn ACL. No bilateral case of ACL rupture was in either of the two groups.

In all 14 cases in the STG-endobutton group radiography was carried out in AP and lateral views postoperatively and at the 1-year follow-up in 1 case and at the 2-year follow-up in 12 cases. The dimensions of the femoral and tibial bone tunnels were measured and corrected for magnification in both views. In the STG-endobutton group the preoperative bone tunnel diameters matching the size of the graft were 8 mm ($n = 1$), 9 mm ($n = 12$), and 10 mm ($n = 1$).

MRI was performed with a 1.5-T imager (Vision, Siemens, Erlangen, Germany) using a standard CP extremity coil. The imaging protocol included the following pulse sequences: sagittal proton density (PD) weighted [2600/16 (repetition time ms/echo time ms)], T2-weighted (2600/98), and fast short-inversion-time inversion recovery images [5500/30/150 (inversion time ms)]. In the oblique coronal view we obtained PD-, T1- (500/12), and T2-weighted images aligned parallel to the reconstructed ACL. In ad-

Table 1 ACL reconstruction with hamstring (STG-endobutton) and patellar tendon (BTB) autografts

	STG-endobutton	BTB	*P*
Age (years)	35	31	NS
Men, women	10, 4	10, 4	NS
Period from injury to operation (months)	15	8	NS
Preoperative	$n = 14$	$n = 14$	
AP laxity, side to side difference (mm)	6.5 ± 3.2	7.6 ± 3.4	NS
Lysholm knee score	71 ± 15	68 ± 19	NS
Tegner activity level (median)	3	3	NS
1 year postoperative	$n = 13$	$n = 13$	
AP laxity, side to side difference (mm)	2.1 ± 2.2	2.1 ± 2.2	NS
Lysholm knee score	88 ± 15	92 ± 8	NS
Tegner activity level (median)	5	5	NS
2 years postoperative	$n = 10$	$n = 12$	
AP laxity, side to side difference (mm)	0.8 ± 1.5	1.3 ± 2.1	NS
Lysholm knee score	92 ± 15	89 ± 21	NS
Tegner activity level (median)	5	6	NS

Table 2 Bone tunnel dimensions on radiography and on MRI in STG-endobutton group

	Postoperative radiography (mm)	2-year postoperative radiography (mm)	2-year postoperative MRI (mm)
Tibial bone tunnel (AP)	8.9 ± 1.0	11.7 ± 1.0	11.4 ± 1.5
Tibial bone tunnel (lateral)	8.4 ± 0.4	11.9 ± 1.3	11.7 ± 1.6
Femoral bone tunnel (AP)	8.9 ± 1.4	13.2 ± 1.8	na
Femoral bone tunnel (lateral)	na	11.9 ± 0.8	12.1 ± 0.8

Fig. 1 **A** AP and lateral knee radiographs 2 days postoperative. A 9-mm drill bit was used in the STG-endobutton ACL reconstruction. **B** Radiographs demonstrating sclerotic margins and marked femoral and tibial bone tunnel enlargement 2 years postoperative (same patient). **C** Oblique coronal T1-weighted *(left)* and sagittal PD-weighted *(right)* MRI 2 years postoperative (same patient). The graft shows low, homogeneous signal intensity *(arrows)*. Intermediate signal intensity shows streaks of periligamentous tissue within and around the ligamentous graft

dition, axial T1-weighted images aligned perpendicular to the tibial bone tunnel were acquired before intravenous administration of gadolinium-DTPA (Magnevist, Schering, Berlin, Germany) contrast agent (0.1 mmol/kg body weight). Finally, the oblique coronal and axial T1-weighted images were repeated for postcontrast evaluation. Slice thickness was 3–4 mm, and field of view (FOV) was 16 cm on all MRI scans. The study protocol was approved by the local ethics committee.

The following MRI findings were recorded: (a) The homogeneity and the signal intensity within the ACL graft in the femoral and tibial bone tunnels, and in the intra-articular portion of the graft. (b) The signal intensity of the periligamentous tissue about the graft and the individual four ligamentous bundles. (c) The pre- and postcontrast images were compared separately for the location and intensity of any enhancement of the graft itself and of the periligamentous tissues. (d) The amount of fluid in the knee joint was evaluated. (e) The AP and sagittal diameters (mm) of the bone tunnels were measured from PD-weighted sagittal and coronal images. These measurement points on femur and tibia were the same on radiography and on MRI 2 years postoperatively.

In statistical analysis the mean and standard deviation of all bone tunnel dimensions were calculated. A paired *t* test was used to assess the statistical difference between immediate postoperative and follow-up radiography in the STG-endobutton group. The linear correlation (Pearson) between the dimensions of the bone tunnels detected on radiography and on MRI was calculated using regression analysis. The χ^2 test and analysis of variance were used in comparing the BTB and STG-endobutton groups.

Results

There were no statistically significant differences between the BTB and STG-endobutton groups with respect to clinical findings, stability tests or knee scores (Table 1). In addition, no statistically significant differences were observed with respect to the International Knee Documentation Committee forms.

On immediately postoperative radiography in the STG-endobutton group the margins of the bone tunnels in femur and tibia were difficult to identify, but the margins were sclerotic and easily detected 1 and 2 years postoperatively. All patients with 1-year (n = 1) and 2-year (n = 12) follow-ups in the STG-endobutton group showed bone tunnel enlargement. On tibial and femoral AP view radiography the diameter of the bone tunnel increased during 2 years of follow-up from 8.9 mm to 11.7 mm (23%, P = 0.003) and from 8.9 mm to 13.2 mm (33%, P = 0.01; Table 2, Fig. 1 A, B). On lateral view radiography there was no statistically significant difference. The bone tunnel dimensions measured on radiography and on MRI 2 years postoperatively on tibial AP and lateral views showed significant correlation: r = 0.58, P = 0.05; and r = 0.77, P = 0.004, respectively (Table 2). The correlation was poor (r = 0.37, P = 0.39) on femoral lateral views. In two cases knee osteoarthrosis had radiologically advanced during the 2 years of follow-up. In all cases the bone tunnel enlargement increased towards the intra-articular cavity being less obvious near the fixation points.

The individual four bundles of the composite STG graft itself showed homogeneous, low signal intensity on all 14 MRI. Periligamentous tissue between the individual bundles of the graft in the femoral and tibial bone tunnels was seen in all cases on axial, coronal and sagittal MRI. The tissue material showed signal intensity identical to hyaline cartilage on PD- and T1-weighted images, and was best observed on coronal T1-weighted images (Fig. 1 C). On axial and coronal T1-weighted images, similar intermediate signal intensity periligamentous tissue between the graft and the bone tunnel was seen in all cases in the distal femoral bone tunnel and in 11 cases in the proximal tibial bone tunnel. In 10 cases, the tibial portion, and in all cases, the femoral portion of the periligamentous tissue showed some longitudinal high signal intensity areas on sagittal short-inversion-time inversion recovery images. The thickness of this tissue was typically 1 mm in the proximal tibial bone tunnel, and it increased slightly towards the intra-articular cavity.

Fig. 2 Sagittal PD-weighted MRI (2 years postoperative) demonstrating slightly thinner low signal intensity STG graft in the intra-articular cavity *(arrow)*

In the intra-articular portion the graft itself showed similar homogeneous, low signal intensity in all cases. The intra-articular periligamentous tissue had longitudinal intermediate signal intensity streaks within and around the graft, best observed on PD- and T1-weighted images. In all cases the ligamentous graft was slightly thinner in the intra-articular cavity, and the periligamentous tissue was more abundant (Fig. 2).

On postcontrast T1-weighted images, the periligamentous tissue within and around the graft showed mild contrast enhancement in 11 cases in the distal portion of the femoral bone tunnel and in the proximal portion of the tibial bone tunnel. There was no detectable contrast enhancement on the periligamentous tissue in the other areas of the femoral and tibial tunnels. Neither was the ligamentous graft itself enhanced by the contrast medium (Fig. 3).

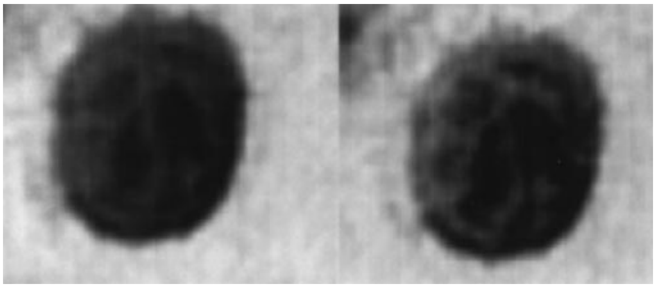

Fig. 3 *Left* precontrast axial T1-weighted MRI (2 years postoperative) demonstrating the tibial bone tunnel 5 mm distal from the intra-articular cavity. The ligamentous graft shows low, homogeneous signal intensity with intermediate signal intensity tissue within and around the graft. *Right* on the postcontrast image, the graft itself shows no increase in signal intensity, and the periligamentous tissue shows mild, homogeneous contrast enhancement

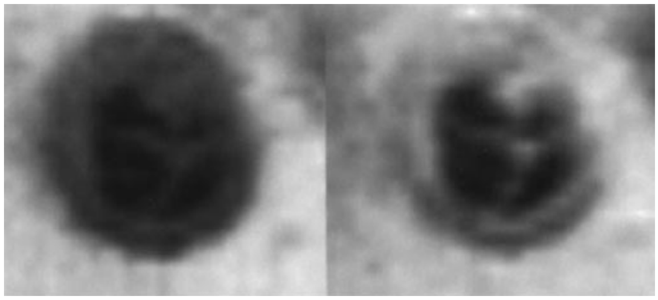

Fig. 4 *Left* precontrast axial T1-weighted MRI (3 months postoperative) demonstrating the tibial bone tunnel 4 mm distal from the intra-articular cavity with abundant periligamentous tissue. *Right* on the postcontrast image, the periligamentous tissue shows marked contrast enhancement in and around the ligamentous graft

Discussion

The individual four bundles of the composite hamstring autograft itself showed homogeneous, low signal intensity on all MRI, an appearance typical to an intact graft [16]. Longitudinal intermediate signal intensity streaks within the graft was an additional observation on sagittal MRI. In all cases the oblique axial images clearly demonstrated that these longitudinal streaks were caused by periligamentous tissue between the individual four bundles of the composite hamstring graft.

According to our contrast-enhanced MRI both femoral and tibial bone tunnels contained excessive contrast enhancing tissue material with appearance similar to fibrous tissue. We suggest that this periligamentous tissue is vascularized and identical to postoperative epidural scar tissue found on contrast-enhanced MRI after surgery of lumbar disc herniation [9, 22]. The individual ligamentous graft was not hypertrophied and displayed no contrast enhancement. In our study, the amount of periligamentous tissue was slightly variable between individual patients. Similar phenomenon is detected on epidural scar tissue in which also the signal intensity decreases with time after surgery [20].

Few studies of bone tunnel enlargement have been published [4, 5, 7, 10, 12–14]. However, the clinical significance and etiology of this phenomenon remains unclear. L'insalata et al. [12] compared radiographic findings after BTB and hamstring reconstruction (endobutton fixation) and found a constant enlargement of the bone tunnels after the endobutton fixation method. Their observation of bone tunnel enlargement by 25–28% at 9–22 months' follow-up time is in the same range as our 23–33% at 2 years' follow-up. Their conclusion as to the cause of this phenomenon was that the points of fixation in the endobutton technique are at greater distance to the knee joint thus creating enlargement of the bone tunnels by a "wind shield wiper" effect. Another possible explanation is propulsion of the synovial fluid or synovial tissue into the bone tunnels with progressive expansion of the bony margins. A solution to avoid the distant hamstring autograft fixation points might be interference screw fixation of the tendons with tight press fit drill channels [1, 15]. In a recent review article Höher et al. [10] discussed the theoretical concepts surrounding the etiology and possible measures for prevention of bone tunnel enlargement [10]. The longitudinal graft motion of the STG-endobutton reconstruction was referred to as the "bungee effect." Their conclusion for prevention of bone tunnel enlargement may be achieved by more anatomical initial graft fixation.

There is agreement that bone tunnel enlargement may occur within the first year after ACL surgery, and no further increase in bone tunnel diameter has been observed from then until 2–3 years after surgery [4, 14]. In our prospective material the widening of tunnel edges has been visible by even 1 year, and the well-defined sclerotic margins on radiography suggest that the process has ceased. Our accelerated rehabilitation protocol with no knee braces and full weight bearing 2 weeks postoperatively may result in early stress on the graft tissue before biological graft incorporation is complete.

The etiology and clinical relevance of ACL autograft revascularization remains unclear. Some authors have suggested that the blood supply of the reconstructed ACL originates from the synovium of posterior joint capsule within 6 months postoperatively [24]. MRI studies of STG autograft by Howell et al. [8] conclude that periligamentous soft tissue was vascularized and covered the graft by 1 month postoperatively. In our study, 3-month postoperative MRI in one patient showed abundant periligamentous tissue with marked contrast enhancement confirming that vascularized fibrous tissue develops shortly postoperative to ACL surgery (Fig. 4).

We found only a poor correlation between sagittal MRI and femoral lateral view radiography. This was probably because our sagittal MRI was customized for imaging the intra-articular portion of ACL and tilted towards the coronal plane. Therefore the orientation of sagittal MRI differed from the femoral bone tunnel, possibly causing the poor correlation. Due to these measurement difficulties we suggest that radiographic measurements are more suitable and reliable in evaluating bone tunnel dimensions in clinical practice.

We conclude that in spite of the alarming appearance of the follow-up radiography in the STG-endobutton ACL reconstruction, the MRI and clinical examinations as well as knee scores and laxity measurements confirm a successful ACL reconstruction and results equaling those of BTB reconstruction.

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