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Implant-free press-fit fixation for bone–patellar tendon–bone ACL reconstruction: 10-year results

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Abstract
Objective The aim of this study is to determine the outcome of anterior cruciate ligament (ACL) reconstruction without foreign material with patellar tendon bone graft in the fixation with bone dowels near the native insertion.
Materials and methods Between 1998 and 1999, 189 patients were operated with ACL reconstruction with BTB patellar tendon graft. In a prospective study, 148 (78%) (91M, 57F) patients could be seen for a mean follow-up of 10.3 years. All had foreign material-free press-fit and a bottom-to-top (BTT) fixation in 120° knee flexion. All patients were evaluated with detailed history, clinical examinations, radiographic examination with weight bearing which could be compared to the time of surgery in 64 (43%) patients. Laxity testing was performed in Lachman position with the Rolimeter and pivot shift. All patients were graded according to the IKDC and Tegner activity score.
Results 87% of the patients achieved an IKDC score of A/B. The subjective IKDC score was A/B in 94.6% of the subjects. The average side-to-side difference was 1.42 ± 0.88 mm for the Lachman test, 97% of the patients were rated between 0 and 2 mm. The pivot-shift test was negative in 90% and was observed with a glide in 7% of the patients. Radiological joint space narrowing was found in the medial compartment in 8 (12.4%) cases, and laterally in 9 (14.1%) cases. All these patients had partial or total meniscus resections. The patello-femoral joint space was reduced in 21 (23%) cases. The Tegner activity score changed from 6.9 pre-injury to 5.0 at the 10-year follow-up.
Conclusion The implant-free fixation of the graft with bone dowels and BTT implantation has good and excellent results after 10 years in more than 80% of the patients. Loss of the meniscus is a main factor contributing to osteoarthritis. Advantages of patellar tendon bone press-fit fixation include anatomical positioning and fast bone-to-bone healing, ease for revision surgery and cost effectiveness.

Keywords Knee · ACL · Press fit · BTB patellar tendon bone · Bone dowels

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Introduction

The gold standard for anterior cruciate ligament (ACL) reconstruction is the bone–patellar tendon–bone or hamstring graft [19, 29]. Many implants attach the graft far away from the anatomical point of insertion. Biomechanical problems and tunnel widening are described [36]. Different implants have been characterized, including absorbable or non-absorbable screws cross-pins, staples, or small plates [11, 30]. All of these cause bone defects [31, 32] with problems in the case of revision operations. A solution to these shortcomings represents implant-free fixation techniques.

First implant-free techniques for ACL reconstruction have been described by Wuschech [50], Hertel [19, 20], later by Boszotta [4] and Pässler [37] and others [2, 17, 38, 44]. Several biomechanical studies compared the press-fit fixation with commonly used hardware fixations. The press-fit fixation has been shown to have similar pullout strength [26, 34, 39, 44, 45] and stiffness [26, 34, 39, 43] compared to fixation with interference screws in animal models. Bone blocks are fully incorporated after a healing

period of 6 weeks [40]. The advantages are low costs and ease for revision.

We developed a foreign material-free press-fit fixation for patellar–bone tendon–bone graft in 1995 [12, 13]. Since 1998 bone dowels could be harvested with diamond instruments in different diameters and guarantee a reproducible press-fit procedure [14]. The bone dowels can likewise be used to close any bone defects at the donor site or after insertion of the graft.

The hypothesis of this study was that patients treated with an ACL reconstruction in an implant-free all press-fit patellar tendon bone technique achieve similar results as those reported with a mini-open press-fit technique [22].

This study evaluated the press-fit fixation with diamond instruments subjectively and objectively using accepted scoring systems at long-term follow-up.

Materials and methods

In a prospective study, we analysed 148 patients (78.3%) out of 189 patients replaced with BTB patellar tendon graft using method described before [14] between 1998 and 1999. One patient had to be excluded because of a tibia plateau fracture after significant trauma 5 years postop and six patients because of re-ruptures. 33 patients did not appear to the follow-up examination (Table 1).

91 males and 57 females could be investigated. The age at index surgery was 38 years (range 15–58). The average follow-up was 10.3 years (Table 2). There have been 11 patients with overweight, 4 with diabetes, none with rheumatoid arthritis.

In 41 (27.7%) cases the index injury occurred during skiing, in 64 (34.2%) cases soccer, in 34 (23%) cases handball and in 9 (6%) cases other activities such as tennis, biking and running. Meniscal lesions detected by arthroscopy were medial in 39%, lateral in 24% and medial and lateral 16%. In 12 cases, the medial meniscus was sutured and in five cases the lateral meniscus was sutured. In all other cases small resections of the meniscus had been necessary.

There were grade II–III lesions of the articular cartilage of the patella in 25 (17%), of the medial compartment in 29 (20%) and of the lateral compartment in 19 (16%) (Table 2).

Table 1 Excluded patients and criteria

Criteria	*N*
Fracture of the tibia head late postop	1
Contralateral ACL injury	1
Re-rupture	5
Re-rupt. + PCL deficiency	1
Investigation not completed or impossible	33

Table 2 Distribution of age, sex, trauma, meniscus and chondral lesions

N	148
Years follow-up	10.3 (9.6–10.8)
Age at trauma	38 (15–58)
M/F	91/57
Trauma: skiing/soccer/handball/others	41 (27.7%)/64 (43.2%)/34 (23%)/9 (6%)
Meniscus lesion: med/lat/both	57 (39%)/36 (24%)/23 (16%)
Arthroscopic chondral lesions outerbridge II–III: patella/med/lat	25 (17%)/29 (20%)/19 (13%)

Four patients had a previous injury between 2 and 5 years earlier. All other patients had the index injury in the previous 12 months and no other ACL reconstruction before.

All patients were scored by the IKDC and Tegner activity scores [47]. Clinical investigation comprised the pivot-shift test and the Lachman test with a side-to-side maximum displacement measured with a Rolimeter. In 64 cases, radiographic examinations were available as weight-bearing AP radiographs. These were compared with pre-operative comparable weight-bearing X-rays.

Surgical technique

The use of diamond grinding instruments (surgical diamond instruments, SDI) gave us a reproducible precision of 0.2 mm for the bone dowels and press-fit fixation in different diameters. The patellar bone cylinder has a diameter of 9 mm. This cylinder is introduced with the central third of the patellar tendon into the 11 mm diamond cutter. The complete graft is harvested with a 9 mm and 11 mm bone cylinder on each side. The tibial and femoral channels are also created with diamond grinding instruments. The diameter of the tibial tunnel is 9 mm. The femoral tunnel is placed at 10/2 o'clock through the anteromedial portal. The minimum depth is 30 mm with 8 mm diameter because of accurate alignment in the notch and rotation of the graft mimics the anteromedial and posterolateral bundles of the ACL (Fig 1). The graft is inserted from the tibial tunnel into the femoral tunnel (bottom to top, BTT).

First the ligament is fixed press-fit with the tibial bone cylinder near the joint entrance close to the intercondylar eminence. At a 120° knee flexion angle the graft is pulled into the femoral channel. The cortico-cancellous bone dowel harvested from the femoral channel is pushed parallel to the graft into the femoral tunnel and fixes the ligament with close proximity to the joint (Figs. 2, 3).

The ligament is tightened in flexion. Close to extension the graft becomes tightened. The femoral fixation is now

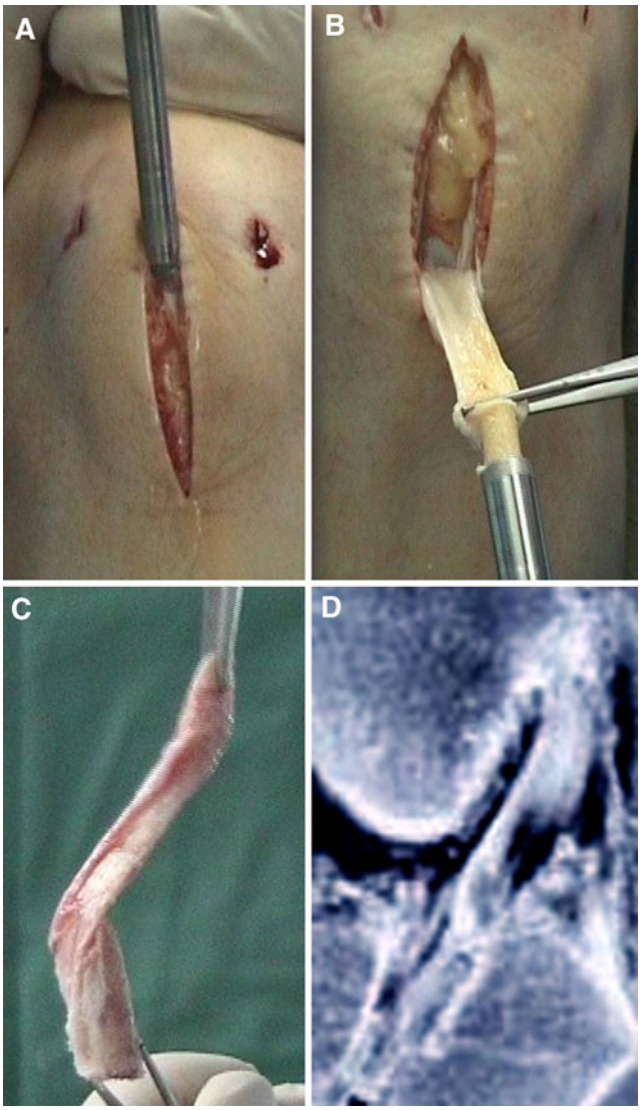

Fig. 1 The 9-mm diamond instrument is grinding a bonecylinder out of the distal patella (**a**). The bonecylinder with the central third of the patellar tendon is pushed in the 11-mm diamond instrument to grind the 11-mm bonecylinder (**b**). The graft is harvested now with a 9-mm bone-tendon 11-mm bone. While rotating the distal BTB-transplant 90° to medial a different tensioning of parts of the tendon can be observed imitating the AM and PL bundle (**c**). An anatomic insertion can be observed in the MRI control (**d**)

attached in an acute angle. In some instances, we have observed some adjusting slippage of the graft from the tibial tunnel.

The tibia bone defect is filled completely with the remaining bone cylinder.

Rehabilitation

The postoperative treatment is based on early functional rehabilitation.

For patients with normal bone quality, extension and flexion are unlimited from the first day.

For those with more osteopenic bone, we restrict the range of movement to between 30° flexion to 90° in a brace for 3–4 weeks. A functional knee brace is worn for 7–8 weeks. Complete weight-bearing is usually achieved after 1 week. Muscle training with electro-muscular stimulation (EMS) starts within the first week. Aquasprint [15] is used after 3 weeks one to two times per week. The patients usually return to office work after 3–4 weeks.

Results

None of the patients returned to follow-up complaining of instability. All patients returned to normal activities such as moderate physical work, running or jogging. 32 (22%) returned to strenuous activities, 43 (29%) returned to very strenuous activities. 63 (43%) returned to their original sport activities. The subjective IKDC score was A/B in 94.6% of the cases. The average laxity in the Lachman position determined with the Rolimeter as maximum side-to-side difference was 1.42 mm with 0–2 mm in 97% of the patients. The pivot-shift test was negative in 90% and demonstrated a glide in 7% of the study population.

Joint space narrowing on weight-bearing radiographs was found in the medial compartment in 8 (12.4%) of the cases, on the lateral side in 9 (14.1%) cases. All these patients had partial or total meniscal resections. The patello-femoral joint space was reduced in 21 (23%) cases.

The objective IKDC score was A/B in 87% of the patients. The Tegner activity score changed from 6.9 to 5.0 (Table 3).

All patients were satisfied and would undergo the operation again.

As donor side morbidity local numbness of skin was reported in 40% of the patients and pain during knee walking on hard ground was described as slight in 41%, moderate in 3% and severe in 2% (Table 4).

Six males and two females had to be revised because of Cyclops problems between 7 and 13 months postop. In the postoperative radiography in one case, the tibia bonecylinder run up too far into the joint. In the next day of arthroscopic revision, it was pushed down and fixed with a kirschner-wire as a crosspin for 6 weeks. One bonecylinder could not be fixed press-fit because of a posterior tunnel blow-out. In this case we went from 10 to 11.30 to high noon position and prepared a new femoral tunnel. Two male patients had an early infection. They were treated successfully with lavage and systemic antibiotic therapy. One patient had a soft tissue infection on the medial port. These three patients were lost to follow-up (Table 5). Meniscus

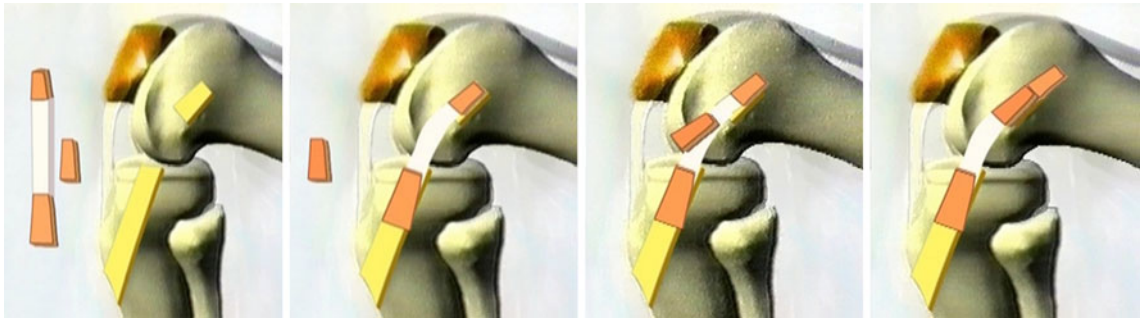

Fig. 2 The BTB-transplant is implanted from distal through the tibia channel. The distal bone cylinder is impacted press fit under the tibia plateau. The proximal bone cylinder is impacted in 120° of knee flexion deep into the femoral channel. The bone cylinder harvested from femoral channel is impacted second and fixes the transplant at the original insertion under tension. After this, BTT (bottom-to-top) fixation the transplant is more tensioned while extending the knee

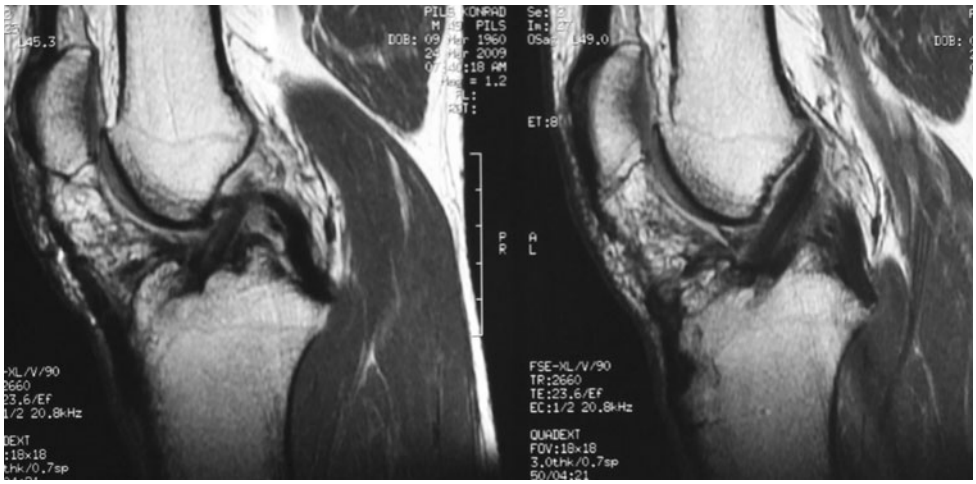

Fig. 3 After 10 years, only few signs of the tibia channel can be detected. The graft is stabile and in correct anatomic position. The magnetic resonance is regular and without artefacts

Table 3 Results of IKDC score, ligament stability and Tegner activity score

IKDC subj A/B	140 (94.6%)
IKDC obj A/B	129 (87.1%)
Lachman average	1.42 ± 0.88 mm
Lachman	
A (0–2 mm)	144 (97.3)
B (3–5 mm)	4 (2.7%)
Pivot shift neg.	133 (89.9%)
Glide	11 (7.4%)
Positive	4 (2.7%)
Tegnera activity	
Pre-trauma	6.9
Follow-up	5

Table 4 Complaints at donor side

Complaints	None	Slight	Moderate	Severe
Kneel soft ground	146 (98.7)	2 (1.3)	0	0
Kneel hard ground	127 (85.8)	21 (14.2)	0	0
Knee walking hard ground	111 (75.0)	32 (21.6)	3 (2.0)	2 (1.3)
Tenderness of skin	146 (98.7)	2 (1.3)	0	0
Numbness of skin	88 (49.5)	46 (31.1)	14 (9.4)	0

revision surgery was needed in 11 cases, twice after a medial suture, once after a lateral suture, 8 after another trauma.

The physical examination showed no collateral or posterior instabilities. An extension deficit according to IKDC categories B/C in between 3° and 10° was seen in 21 (18.2%) of the patients and a lack of flexion (IKDC B/C) between 6° and 25° in 15 (10.1%) patients. One patient (0.7%) presented with a flexion deficit of 30° (IKDC D).

The anterior stability was performed with a Rolimeter in 25° Lachman position as a maximum manual test. The differences between the operated knee and the non-operated knee were with an average difference of 1.42 mm (0–5 mm) and graded IKDC A (0–2 mm) in 144 (97.3%). From these 65 (43.9%) patients had 0–1 mm difference, 72 (48.6%) had a difference of 1–2 mm, 7 (4.7%) had 2–3 mm difference

Table 5 Complications in this study

Complications	
Loosening of the boneplug	
Tibia	1
Femur	1
Graft necrosis	0
Cyclops	8
Retear of meniscus	11
Fracture	0
Infection	3
Thrombosis	3

and 4 (2.7%) had 3–5 mm difference to the opposite knee. The pivot shift was negative in 133 (89.9%) patients. A glide was detected in 11 (7.4%) and in 4 (2.7%) there was a gross pivot shift. These 3% also demonstrated less anterior knee stability (3–4 mm difference).

In the one leg hop test according to IKDC, 134 patients scored A (90.4%) and B/D 14 (9.5%; Table 6).

Discussion

This study presents long-term follow-up after foreign material-free press-fit patellar tendon bone ACL reconstruction with a BTT graft tensioning. The clinical results compare well with previous reports on ACL reconstructions [18]. At 5 or more years of follow-up, normal or nearly normal IKDC scores were reported between 75 and 95% [1, 10, 21, 22, 24, 25, 27, 28, 38, 41, 42, 46].

Basic science studies could show that secure osseous integration and histological observation of a tide mark could be observed as early as 4–6 weeks post-ACL reconstruction [40, 48]. High stability of the graft in press-fit fixation could be demonstrated with original bone dowels [26, 34, 39, 45] and ceramic dowels [33]. This supports our early functional rehabilitation [15]. In this study, all patients began complete weight-bearing between 5 and 10 days postop. Isometric training for the medial vastus of the quadriceps muscle started from the first day postop. In the third week, patients could start AquaSprints [15]. The BTT fixation and tensioning of the graft has been working in most case. No early failures have been observed in this study.

Press-fit fixation depends on the quality of bone and bone mass, which was subjectively evaluated in this study. In some patients with osteopeneic bone, we used a more protective postoperative protocol. Experimental studies have shown that during passive flexion extension of 0°–30°–120°, there is very limited load on the ACL. These cases limited to a reduced range of movement in a brace from 30° to 90° knee flexion for the first 3–4 weeks. After this treatment, rehabilitation was equal to the other patients.

Table 6 Results on the basic of the IKDC knee examination from 2000

Groups (n = 148)	A [n (%)]	B [n (%)]	C [n (%)]	D [n (%)]
Patient subjective assessment	62 (41.9)	78 (52.7)	8 (5.4)	0
Symptoms	135 (91.2)	11 (7.4)	1 (0.7)	1 (0.7)
Range of motion: lack of extension	117 (79.1)	24 (16.2)	7 (4.7)	0
Range of motion: lack of flexion	132 (89.2)	11 (7.4)	4 (2.7)	1 (0.7)
Rolimeter difference	144 (97.3)	4 (2.7)	0	0
Pivot shift	133 (89.9)	11 (7.4)	4 (2.7)	0
Compartmental findings				
Crepitus patello-femoral	31 (20.9)	63 (42.6)	48 (32.4)	6 (4.1)
Crepitus medial compartment	138 (93.2)	10 (6.8)	0	0
Crepitus lateral compartment	141 (95.2)	7 (4.8)	0	0
X-ray findings (n = 64) compared to time of surgery				
Patello-femoral joint space	43 (67.2)	13 (20.3)	8 (12.5)	0
Medial compartment joint space	56 (87.5)	6 (9.3)	2 (3.1)	0
Lateral compartment joint space	55 (85.9)	7 (10.9)	1 (1.6)	1 (1.6)
X-ray findings (n = 58) weight bearing				
Patello-femoral joint space	41 (70.7)	11 (17.0)	6 (10.3)	0
Medial compartment joint space	49 (84.5)	7 (12.0)	2 (3.5)	0
Lateral compartment joint space	50 (86.2)	7 (12.0)	1 (1.7)	0
Function test (one leg hop)	134 (90.5)	7 (4.7)	7 (4.7)	0
Final evaluation	38 (25.7)	91 (61.5)	17 (11.5)	2 (1.3)

IKDC results: *A* normal, *B* nearly normal, *C* abnormal and *D* severely normal

The long-term follow-up showed no difference between the osteopenic group and the patients with normal bone quality. In no case did we have a problem with the BTT tensioning technique. The technique has been forgiving and usable in every case in our hands. Since 1995, except of one kirschner-wire, we have not used any foreign material for graft fixation. The bone dowels enhance a pure press-fit fixation in both femur and tibia.

To our knowledge, this is the first study investigating bone–tendon bone–patellar ligament grafts with two different diameters of the bone cylinders.

Press-fit fixation includes undisturbed bone-to-bone healing and avoidance of the disadvantages associated with hardware fixation, such as graft laceration, bioincompatibility, biodegradability or allergic reactions [31, 32].

A fixation of the graft close to the native insertion is beneficial [23]. This minimizes the risk of tunnel enlargement [5, 22, 35]. In this study, the femoral insertion of the transplant is located at 10/2 o'clock. It is aimed with a guiding device through the anteromedial port at the native insertion. The press-fit fixation also fixes the graft in a crescent-shaped footprint around the entrance to the 8.5 mm femoral tunnel. This causes the area of fixation at the femoral end to be similar to that of the bundles of a native ACL (Fig. 1). The graft is positioned and rotated according to the native ACL. We have observed the tensioning of the posterolateral and anteromedial bundles. This is in accordance with the findings of Hertel [22].

Osteoarthritis development post-ACL reconstruction is reported for all types of reconstructions [9, 16, 27]. The reason can be an individual factor for OA, overuse in stable knees, non-anatomical reconstruction, meniscus lesions or other lesions.

In our study, we found a mild-to-moderate joint space narrowing in 24% according to the IKDC standard form and for the patello-femoral joint in 27%. This includes patients with beginning arthritic changes prior to the ACL reconstruction. Stability did not correlate to arthritic changes, nor did instability. Meniscus surgery was the major reason for arthritic changes, especially lateral meniscus surgery. This compares to other results [7, 22, 25].

Donor site morbidity is a major concern for the use of patellar tendon bone transplants. In this study, 24% of the patients with patellar BTB graft complained about discomfort while knee walking. This may depend on a shallow graft harvest and refilling the bone defect of the tibia (Fig. 3). This result is equal or better to the results of Hertel [22], Müller [36] and Kartus [29]. Fracture of the patella is a rare complication [3, 6, 8, 49]. Over the years no patella fracture has happened with the BTB replacement in this technique. Most press-fit fixations remained stabile. No excessive tunnel widening was seen in this study.

Conclusions

The implant-free all press-fit method for the BTB graft has excellent and good results in most cases after 10 years. The diamond instruments support a reproducible technique for foreign material-free press-fit fixation. The BTT implantation and tensioning of the graft proved its feasibility. Advantages of patellar tendon bone press-fit fixation include anatomical positioning and fast bone-to-bone healing, no disadvantages associated with hardware, no need for the removal of foreign material, ease for revision surgery and cost effectiveness. Meniscal resection is a main factor for an increase of osteoarthritis.

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