Improved outcomes after anterior cruciate ligament reconstruction with quadrupled hamstring autografts and additional bone plug augmentation at five year follow-up

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Abstract

Purpose Hybrid fixation has been proposed to improve outcomes of anterior cruciate ligament (ACL) reconstructions. This study evaluated midterm outcomes after transfemoral graft fixation using either a conventional or a modified technique using additional bone plug augmentation (BPA) of the femoral tunnel aperture.

Methods Seventy-one consecutive patients undergoing ACL reconstruction using a quadrupled hamstring autograft with transfemoral graft fixation and tibial interference screw fixation were included. Of these, 56 patients could be followed up 61 months (range 52–69 months) after ACL reconstruction both clinically and by magnetic resonance imaging (group A, conventional technique, $n=34$; group B, modified technique, $n=22$). Anteroposterior (AP) laxity measurements and International Knee Documentation Committee (IKDC), Lysholm and Tegner activity scoring were performed, while imaging included assessment of bone tunnel diameters, graft condition and graft filling at the femoral bone tunnel aperture.

Results Patients with additional BPA had a significantly higher degree of graft filling at the femoral bone tunnel

aperture ($p=.0135$) and ‘healthier’ grafts ($p=.0495$). They also tended to display less AP laxity difference in terms of mean differences and total patient numbers. Lysholm, IKDC and Tegner activity index scores and bone tunnel diameters were not significantly different.

Conclusions Additional BPA is an easy-to-perform, cheap and safe manoeuvre, which has the capacity to improve morphological and clinical outcomes at five year follow-up. However, femoral tunnel widening is unaffected by additional BPA.

Introduction

Anterior cruciate ligament (ACL) reconstruction with hamstring autografts has gained popularity recently. While many fixation systems are available, optimum graft fixation remains controversial. Transfemoral pins are promising because of their superior biomechanical properties [1] and clinical outcomes [2]. However, significant bone tunnel widening (TW) has been observed for this fixation method at short-term follow-up [3]. Although the overall amount of tunnel widening was not found to be correlated with functional outcomes in terms of knee stability and function [4, 5], it seems reasonable to try to avoid or at least to reduce it.

A proven preventive approach is to insert a spongy bone plug into the graft-laden bone tunnel in a ‘press-fit’ manner (Fig. 1a) [6–8]. The rationale behind this procedure is three-fold: First, graft-tunnel interface micromotion is thought to be eliminated and the extent of secondary TW thus reduced [9]. This is especially relevant in extra articular fixation techniques, where unequal diameters of tendon loops and bundles cause incomplete graft tunnel filling (Fig. 1b). Second, bone plug augmentation (BPA) may improve biological graft integration as it reduces the circulation of cytokine-

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Fig. 1 Transfemoral cross-pin fixation technique with (a, group B) or without (b, group A) additional bone plug insertion (green hamstring graft, blue transfemoral cross-pin, light blue bone plug, grey bone tunnel)

rich synovial fluid at the interface, which contributes to inflammatory bone osteolysis and subsequent TW [10]. Third, additional BPA has been demonstrated to improve initial construct fixation stiffness [6, 11].

Despite promising short-term outcomes [7, 8], little data are available on the mid- to long-term effects of additional BPA in ACL reconstructions. Thus, this study investigated the effects of transfemoral fixation in combination with BPA at five year follow-up in terms of morphological and clinical outcomes. The hypothesis was that additional BPA of the femoral bone tunnel would improve the graft condition and tunnel fill, enhance knee stability and function and decrease TW.

Methods

From October 2001 to October 2002, 104 consecutive patients underwent ACL reconstructions with hamstring autografts in our institution. These were performed by two experienced surgeons using the same overall operative technique, equipment and assistants. Biodegradable transfemoral devices

(BioTransfix®, Arthrex, Naples, FL, USA) were used for femoral-sided and poly-L-lactic acid (PLLA) interference screws (DeltascREW®, Arthrex) for tibial-sided graft fixation. Inclusion criteria were defined as follows: (1) unilateral ACL rupture, (2) normal contralateral knee, (3) no previous knee ligament surgery, (4) no malalignment, (5) no osteoarthritic changes and (6) no additional knee ligament injuries. Of the consecutive series of 104 patients, 71 qualified for study inclusion and were enrolled. Patients either received conventional (group A) or bone plug-augmented (group B) ACL reconstructions as described below. Patient randomisation and group allocation were defined by the sterile availability of the bone inserter in the OR at the time of surgery.

Of the 71 patients included, 56 patients (group A, $n=34$; group B, $n=22$) could be followed up completely after about five years in terms of clinical and imaging examinations (follow-up rate 79 %). For follow-up patient demographics please refer to Table 1. Dropout patients could either not be located ($n=11$) or lacked time or inclination to undergo follow-up examinations ($n=4$).

Study approval from the relevant Institutional Ethics Committee and individual patient consent were obtained prior to inclusion in the study.

Surgical technique and rehabilitation

Semitendinosus and gracilis tendons were harvested and prepared to create a quadrupled autograft. Tibial tunnels were positioned within the ACL footprint and created equal to graft size; then the femoral tunnel was placed transtibially at the 11 and 1 o'clock positions, respectively, using K-wires through a 6-mm offset guide. In patients undergoing conventional ACL reconstruction (group A) the K-wire was overdrilled with a drill bit according to graft size, while in patients undergoing the modified surgical technique with additional BPA (group B) a 7-mm drill bit was advanced 2 mm into the femur to create a drill footprint for bone plug harvesting. The drill footprint was used to guide a 7-mm rounded tube harvester (AR-1980-07, OATS® Set, Arthrex) into the femur, which was advanced 30 mm, rotated and

Table 1 Patient demographics within treatment groups ($n=56$)

	Group A (conventional technique)	Group B (modified technique)
Number of patients	34	22
Age at surgery (years), mean (range)	33 (15–61)	34 (18–56)
Male/female	14/20	12/10
Right/left knee	20/14	14/8
Average time from surgery to follow-up examinations (months)	61.4±4.0	61.2±3.8

extracted. Thereby, a spongy bone plug approximately 6 mm in diameter and 25–28 mm in length was harvested (Fig. 2a). Afterwards, the canal was overdrilled according to graft size and a guide pin was drilled through the guide sleeve perpendicular to the femoral bone tunnel. Afterwards, the lateral femoral cortex was broached with a five mm broach. The guide pin was used to transport a flexible nitinol graft passing wire through the femur. After retraction of the guide sleeve, the hamstring graft was pulled through the tibia and into the femoral bone tunnel. Transfemoral graft fixation of the graft was achieved by the insertion of a biodegradable intraosseous pin (BioTransfix®, Arthrex) inserted over the nitinol wire and perpendicular to the femoral tunnel (Fig. 1a). In group B patients, the harvested bone plug was inserted into the femoral bone tunnel by interference fit with a tubed delivery instrument (AR-1240-07, Bone Inserter, Arthrex) at 120° flexion (Figs. 1b and 2b).

Finally, in both groups tibial-sided graft fixation was achieved with a biodegradable PLLA interference screw (DeltascREW®, Arthrex), which was oversized 2 mm and inserted press-fit antegrade into the tibial tunnel. Distal graft fixation was performed in full knee extension under manual tension. Postoperative rehabilitation was conducted using

Fig. 2 a Rounded tube harvester with bone plug. b Arthroscopic view of bone plug in situ

established standards with full weight-bearing and knee extension allowed right away. Braces were worn for six weeks with flexion being limited to 90°. Return to sports was permitted after six to eight months.

Postoperative radiographic examination

Standardised radiographs [anteroposterior (AP) and extension lateral views] with magnification markers in place were taken after surgery. If possible, the femoral tunnel was identified and tunnel sizes were measured on both views at notch level, at the central segment and at the femoral tunnel ending, i.e. at the graft suspension point. Measurements were taken perpendicular to the long axis of the bone tunnel by an experienced musculoskeletal radiologist.

Mean tunnel diameters were calculated for each level and for the entire femoral bone tunnel. Femoral tunnel sizes thus measured were correlated to drill bit sizes used intraoperatively to evaluate whether radiographic determination of diameters matched drilled tunnel diameters.

Follow-up examinations

At follow-up, patients were re-examined clinically according to the International Knee Documentation Committee (IKDC) [12], Lysholm [13] and Tegner activity index scores [14]. The Rolimeter device (Aircast, Boca Raton, FL, USA) was used to determine AP laxity in both knees at 70° flexion; from these values the side-to-side difference was calculated.

Morphological assessment was conducted on the basis of coronal, oblique sagittal and axial magnetic resonance imaging (MRI) scans performed on a 1.5-T MR imager (Vista Polaris, Philips, Best, The Netherlands). By using a standard extremity coil visualisation of a quadratic field of view of 16 cm with a slice thickness of three to four mm was achieved. Imaging protocols included proton density-weighted, T1- and T2-weighted spin echo sequences. Morphological evaluation was performed by a senior musculoskeletal radiologist and two orthopaedic surgeons individually; differences in assessment were discussed until consensus was reached.

Tunnel widening

Femoral bone tunnel diameters were measured perpendicular to the tunnel axis on coronal and sagittal views using the digital calliper of the imaging software used (K-PACS v1.6, Image Information Systems Ltd., London, UK). Bone tunnel diameters were determined on three femoral heights as outlined above. Again, mean tunnel diameters were calculated for each level with the measurements taken from each plane. Changes in tunnel size were calculated as compared to the diameter of the original drill bit used at surgery; a difference

Fig. 3 MRI scans (oblique sagittal reconstructions, T2-weighted) ▶ 5 years after ACL reconstruction exemplifying different degrees of hamstring graft filling of femoral bone tunnels at notch level. **a** Partial graft filling (37-year-old man, group A). **b** Intermediate graft filling (47-year-old woman, group B). **c** Complete graft filling (35-year-old man, group A)

greater than 2 mm was considered to be significant tunnel widening.

Graft condition

The condition of the hamstring graft was evaluated by its signal intensity and morphology according to a modified version of a classification first described by Rak et al. [15]. Patients were divided into three groups depending on the condition of their grafts [hamstring graft condition score (HGCS)]: (1) low-intensity signal, thick and tensioned; (2) intact, but slightly sloppy, low to intermediate signal intensity; and (3) thinner, sloppy, intermediate signal intensity.

Graft filling

The extent to which the graft filled the femoral bone tunnel at notch level was assessed on oblique sagittal views and classified as partial, intermediate or complete (Fig. 3). The diameters of both the femoral bone tunnel and the hamstring graft were measured perpendicular to the long axis of the tunnel at the tunnel aperture and a graft filling coefficient [$c = \text{diameter}_{\text{graft}} / \text{diameter}_{\text{tunnel}}$] was calculated. A filling degree of $c \leq 70\%$ was termed partial (score 1), $70\% \leq c \leq 90\%$ intermediate (score 2) and $c \geq 90\%$ complete (score 3).

Statistical evaluation

Statistical analyses were conducted with SPSS using unpaired *t* tests and chi-square tests (SPSS 16.0, SPSS Inc., Chicago, IL, USA). Pearson's correlation coefficient was used to determine correlation between tunnel sizes as obtained from the operative notes and as measured on postoperative radiographs. Data are expressed as mean $\pm$ standard deviation, median (range), absolute numbers (*n*) or percentages (%). Significance levels were set to $p < .05$.

Results

All 56 patients could be re-evaluated with complete clinical and MRI examination after 61 months on average (range 52–69 months).

The degree of graft filling of the femoral bone tunnel at notch level was significantly improved in group B patients in terms of average scores and total patient numbers (Table 2).

Table 2 Degree of graft filling at the femoral bone tunnel aperture as assessed on oblique sagittal MRI views. Filling degrees of $c \leq 70\%$ were termed partial (score 1), $70\% \leq c \leq 90\%$ intermediate (score 2) and $c \geq 90\%$ complete (score 3)

	Group A	Group B	Statistics (<i>p</i> value)
Partial (<i>n</i>)	18	4	.0317
Intermediate (<i>n</i>)	9	9	
Complete (<i>n</i>)	7	9	.0135
Average score	1.68±0.81	2.23±0.75	

Likewise, group B patients displayed significantly ‘healthier’ grafts as indicated by lower average graft scores. In terms of absolute patient numbers this difference tended towards but did not reach significance (Table 3).

On follow-up MRI scans, bone plugs had undergone complete osseous resorption and were not distinguishable from surrounding bone tissue. No free intra-articular fragments were noted.

On postoperative radiographs, femoral bone tunnel margins could be definitely made out in 24 patients (43 %), while in all other patients tunnel margins could not be definitely distinguished. In terms of inter-method correlation tunnel sizes on postoperative radiographs were significantly correlated to drill bit sizes used at surgery ($r=0.9150$, $p<.0001$).

Tunnel sizes of two patients in group A could not be evaluated due to excessive drill bit abrasion and MRI signal distortion. On average, drill bit size at surgery was 7.62 mm (group A) and 8.00 mm (group B), respectively, while at follow-up, mean bone tunnel diameters had increased in all segments measured, regardless of BPA. Overall, significant average femoral TW (in excess of 2 mm) was found in 23 of 32 (72 %, group A) and 15 of 22 (68 %, group B) patients evaluated ($p=.7718$). This equalled average increases of 2.3 ± 1.4 mm (21 %, group A) and 2.5 ± 1.3 mm (22 %, group B) ($p=.7139$).

When examined clinically, no statistically significant differences were found between groups in terms of functional scores and AP laxity side-to-side differences; yet group B patients tended to be more stable (Table 4).

Table 3 Hamstring graft condition at follow-up. Scoring was performed using a modified version of Rak’s classification of MRI graft morphology [15]

	Group A	Group B	Statistics (<i>p</i> value)
Average score	1.81±0.75	1.41±0.67	.0495
HGCS 1 (<i>n</i>)	13	15	.0892
HGCS 2 (<i>n</i>)	14	5	
HGCS 3 (<i>n</i>)	7	2	

HGCS hamstring graft condition score

Table 4 Clinical outcomes. AP laxity was determined in both knees at 70° of flexion and the side-to-side difference calculated (*). IKDC grading was performed according to IKDC guidelines [12]

	Group A	Group B	Statistics (<i>p</i> value)
AP laxity difference			
IKDC A, ≤ 2 mm (<i>n</i> /%)	28/82	21/95	.3110
IKDC B, 3–5 mm (<i>n</i> /%)	4/12	1/5	
IKDC C & D, ≥ 6 mm (<i>n</i> /%)	2/6	0/0	.2297
Average AP laxity difference (*) (mm)	1.2±1.7	0.7±0.9	
Average Lysholm score	91.5±8.0	86.4±14.6	.0960
Average subjective IKDC score	82.2±14.4	85.6±14.8	.3997
Average Tegner activity index score preinjury	6 (2–9)	5.5 (3–10)	.8235
Average Tegner activity index score at 5 years postsurgery	5 (2–9)	4 (1–9)	.2739

IKDC International Knee Documentation Committee

Discussion

The most important finding of this study was that additional BPA of the femoral tunnel significantly improved morphological outcomes of ACL reconstructions at midterm follow-up. Although all bone plugs were entirely resorbed, hamstring graft filling and condition were found to be significantly improved. Likewise, bone plug-augmented patients tended to display less AP laxity difference, while no effects upon femoral TW were noted.

Graft filling was significantly better although tunnel diameters were about equal and bone plugs not clearly distinguishable. Bone plugs must have exerted their effects in the short- to midterm not evident at follow-up. Thus enhanced graft integration may be explicable by recent findings on tendon-to-tunnel healing. The biomechanical and histological quality of this interface was found to depend on the degree of compression applied. Weiler et al. demonstrated significantly improved insertion site healing in areas of maximum interference screw compression [16]. Additional press-fit BPA could equally create such a situation, at least initially as it reduces the tunnel cross-sectional area and allows circumferential tendon-to-bone contact [7]; thereby bone plugs may help to maintain improved graft quality in the long term. Moreover, bone plugs may reduce ‘dead space’ and intrusion of cytokine-rich synovial fluid and/or may deliver biologically active substances to the healing site [7].

BPA knees tended to be more stable in terms of mean AP laxity and patients with moderate or massive laxity differences. Functional clinical assessment scores did not demonstrate any significant differences, which may be due to the relatively low sensitivity and specificity demonstrated for clinical scores in the detection of minimal changes [17].

Additional BPA could not prevent femoral TW although a reduction of interface micromotion, which is the predominant aetiological factor in theories on TW [10], due to superior biomechanical properties has been suggested. Several authors found fixation constructs augmented with cancellous bone plugs had higher stiffness values and pullout forces than fixation constructs alone [6, 11]. Clinically, BPA significantly decreased the cross-sectional tunnel area [7] and effectively prevented TW in the short term [8]. All these findings are contrary to our data indicating no such effect. In our study, bone plugs were spongy and not compacted at the time of surgery, hence they may not have had an effect in the first months after surgery, i.e. at the time when TW occurs [18, 19]. In that instance, TW was the result of stronger mechanical and biological mechanisms [10].

Matsumoto et al. studied the dynamics of tunnel size development and its alteration due to BPA. They observed cross-sectional tunnel areas to be significantly smaller on the day of surgery and limited to the tunnel size produced at surgery after one to two years [7]. Hence, assuming BPA to be effective, their insertion may have delayed TW in our patients too, at least temporarily, as bone plugs were resorbed and lost effectiveness. Hence, tunnel consolidation also seems to depend on factors such as bone density, graft fixation and integration and rehabilitation.

Study limitations involve the different imaging modalities used to determine femoral bone tunnel sizes, which may have been a source of inaccuracy. As drill bit diameters and tunnel sizes were highly significantly correlated, possible drill bit chatter may be excluded. Hence, drill bit diameters may be used as baseline tunnel sizes. For lack of an MRI scan performed after surgery, this study has to assume that femoral tunnel sizes produced at surgery will be measured at that same size by MRI. Follow-up examinations were performed by MRI instead of conventional radiography as individual patient's radiation exposure was to be limited.

Limited subgroup sizes after allocation may have limited study power and increased the potential for beta error, i.e. failure to detect a difference when one exists, especially regarding clinical outcomes. However, as statistically significant differences could be demonstrated for morphological scores, the data seem sufficient for statistical analyses. The retrospective design of this study may have been a source of bias, as patient allocation was not conducted in a blinded manner and groups were not fully matched.

At the time of study, femoral tunnels were drilled trans-tibially, which may have been a contributing factor to femoral tunnel expansion [20]. With the surgical technique evolving further, the anteromedial portal is now favoured [9, 21].

In conclusion, additional BPA in combination with trans-femoral graft fixation improves graft morphology and tunnel filling. Equally, clinical outcomes tended to be improved, while TW was unaffected.

Conflict of interest The authors declare that they have no conflict of interest.

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