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A two- and five-year follow-up of clinical outcome after ACL reconstruction using BPTB or hamstring tendon grafts: a prospective intervention outcome study

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Abstract

Purpose The aim of the present study was to evaluate and compare objective and subjective outcome in patients 2 and 5 years after anterior cruciate ligament (ACL) reconstruction with either bone-patellar tendon-bone (BPTB) or hamstring grafts. The second aim was to report the prevalence of re- and contralateral ACL ruptures.

Methods Sixty-eight patients (BPTB, $n = 34$ and hamstring graft, $n = 34$) were evaluated preoperatively, 2 and 5 years after ACL reconstruction. Anterior knee laxity and rotational knee joint stability, muscle torque, hop length, anterior knee pain, activity level and self-reported knee function and quality of life were evaluated within and between groups. The prevalence of re- and contralateral ACL ruptures was also recorded.

Results No significant difference in anterior knee laxity, rotational knee joint stability, hop length anterior knee pain or knee function and quality of life were noted at the 5-year follow-up. No significant differences in concentric or eccentric quadriceps torque at 90°/s and 230°/s were found at any of the follow-ups between and within grafts. A significant group difference in hamstring torque 1.05 (0.02) for BPTB and 0.89 (0.02) for hamstring grafts, and in hop length (leg symmetry index) follow-up 0.94 (0.07) for BPTB compared to 0.99 (0.07) for hamstring grafts ($P = 0.002$) was found at the 2 year follow-up in favour of the BPTB graft, but not at the 5 year follow-up. A significant improvement over time, irrespective of graft, was found in the KOOS′s subscales Sport/Rec and quality of life ($P < 0.001$). None of the patients, irrespective of group, returned to their pre-injury level of sport ($P < 0.05$). Over the five postoperative years, one man and eight women (13 %) (hamstring graft, $n = 5$ and BPTB graft, $n = 4$), sustained a total of 11 (16.2 %) new ACL ruptures: seven (10.2 %) re-ruptures and four (5.9 %) ruptures of the contralateral ACL.

Conclusions At the 5-year follow-up, there were no significant differences in terms of anterior knee laxity, rotational knee joint stability, muscle torque, anterior knee pain, hop performance, quality of life or activity level between patients who had undergone reconstruction with BPTB or hamstring grafts. None of the patients, irrespective of group, had returned to their pre-injury level of activity. Eight out of the nine patients who had sustained a second ACL rupture were women.

Level of evidence II.

Keywords Activity level · Anterior knee laxity · Contralateral ACL rupture · Knee function · Knee instability · Re-rupture

Introduction

The primary goal of ACL reconstruction is to restore mechanical knee joint stability and thereby knee function. The role of rehabilitation is to reduce comorbidity and to support the goals of athletic patients in terms of returning

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to sports [1]. The graft choice for ACL reconstruction for optimal clinical outcome still remains controversial [8, 12, 22, 26, 32, 41]. In two recent systematic reviews, a possible correlation between bone-patellar tendon-bone (BPTB) graft and osteoarthritis was found [24, 32, 41]. Furthermore, it was reported that hamstring graft tendon harvest reduces hamstring muscle strength for approximately 1–2 years and also led to more tunnel widening than the BPTB graft [32].

During recent years, several reports with 2–15 years follow-ups [2, 12, 15, 18, 33, 40] have been published, showing that the quadriceps and hamstring muscle strength are significantly reduced compared to the contralateral uninjured leg [12, 18] independent of graft and that reduced strength in terms of power of the lower leg is strongly correlated with the harvest site [2]. In a 9-year follow-up, Wipler et al. [40] reported a significant difference in favour of the hamstring graft with respect to anterior knee laxity, kneeling, knee walking and the one-leg hop test. In contrast to their results, Gifstad et al. [12] reported no significant differences in anterior knee laxity, activity level or subjective functional knee status and quality of life at a 7-year follow-up between patients who had undergone ACL reconstruction with BPTB or hamstring graft. In a recent Cochrane review, conducted by Mohtadi et al. [28], it was concluded that there is insufficient evidence to draw conclusions on differences between the two grafts for long-term functional outcome. Further, despite satisfactory functional outcomes and regardless of graft choice, lower than expected rates of return to sport after ACL reconstruction are presented in the literature [5, 10, 17].

Graft rupture is one of the most devastating complications after ACL reconstruction. In a recent systematic review [24], it was concluded that the risk for sustaining a graft-failure is similar for BPTB and hamstring grafts. The proportion of re- and contralateral ACL injuries has been shown to increase over time [21]. Wright et al. [41] found a pooled percentage rate of ipsilateral graft rupture of 5.8 % and contra lateral graft rupture of 11.8 %, at a minimum 5 years after ACL reconstruction. The risk ratio for sustaining a *primary* ACL rupture is higher in women than men [33]. However, women are not reported to be at a higher risk for re- or contralateral ruptures of the ACL when compared with men [34].

Clinical results from 7 months and 2 years post surgery have been published previously about a group of patients who have undergone ACL reconstruction with BPTB or hamstring grafts [14, 15]. The aim of the present investigation was to evaluate and compare clinical outcome in this cohort 2 and 5 years after ACL reconstruction and to report the prevalence of re- and contralateral ACL ruptures.

Table 1 Demographic data for patients who have undergone ACL reconstruction with bone-patellar tendon-bone (BPTB) graft ($n = 34$) or hamstring graft/s ($n = 34$)

	BPTB graft ($n = 34$)	Hamstring graft ($n = 34$)
Males/females (*n*)	22/12	14/20
Age, years (mean, SD)	29 (7)	30 (9)
Height, metre (mean, SD)	1.75 (0.08)	1.73 (0.09)
Weight, kg (mean, SD)	75.1 (10.1)	72.4 (11.9)
BMI, kg/m^2 (mean, SD)	24.3 (2.4)	24.2 (2.9)
Injured leg (*n*, left/right)	15/19	13/21
Time between injury and surgery (months, median, lower and upper quartile)	7.8 (5–12)	8.5 (5–18)
Semitendinosus graft alone (*n*)		23
Semitendinosus + gracilis graft (*n*)		11
Medial meniscus injury (*n*)	11	7
Lateral meniscus injury (*n*)	6	8
Patella cartilage damage (*n*)	3	4
Tibia cartilage damage (*n*)	3	3
Femur cartilage damage (*n*)	7	9
Medial collateral ligament injury (*n*)	2	1

Materials and methods

Patients

Between 1999 and 2005, 80 ACL-injured patients, stratified for gender and who met the inclusion criteria, were invited to participate. All patients were referred from experienced surgeons and had undergone a preoperative rehabilitation programme at a Sport Rehabilitation Clinic. Six men and six women declined to participate; therefore, 68 patients, 36 men and 32 women, were finally included in this study (Table 1). The patients were all involved in physical activity or sports with median Tegner activity scale of 7 (range 3–10) before index injury.

Rehabilitation

All patients started a standardized postoperative rehabilitation programme within 1 week after surgery at the same outpatient clinic. No brace was used during the rehabilitation period. Immediate weight bearing according to tolerance was allowed after surgery. Supervised physiotherapy was performed two to three times a week as long as the patient and the physiotherapist considered it necessary. The number of training sessions, the content of the rehabilitation programme, detailed information regarding volume (set, repetition and external loading) and duration (minutes) for each exercise over the first 3 months of the rehabilitation has been described earlier [14, 15].

Evaluation methods

Originally, all patients were evaluated by two experienced independent examiners within 4 weeks prior to surgery and at 3, 5, 7, 9, 12 as well as 2 and 5 years (median 61.5 months, range 60–84) after surgery. Clinical outcomes from baseline and at 2 and 5 years after surgery are reported in the present study. Since significant differences in clinical outcome between grafts were found in the previously published 2-year follow-up study, we found it valuable to include data from that test occasion also in the present study. The evaluation involves objective and subjective methods, and all measurements at each test occasion were carried out in the order presented below.

Objective measures

Anterior knee laxity was measured bilaterally at approximately 20° of knee flexion at 30 lb and manual max with the KT-1000 arthrometer (MEDmetric, Corp., San Diego, CA, USA) [42].

Rotational knee joint stability (lateral subluxation of the femur) was measured using the pivot shift test and recorded according to the standards of the International Knee Documentation Committee (IKDC) [13].

The Kin-Com® dynamometer (Chattex Corp., Chattanooga, TN, USA) [9] was used for measuring concentric and eccentric muscle torque of the quadriceps and hamstring muscle groups bilaterally at 90°/s as well as 230°/s within 90°–10° of knee flexion, always starting with the contralateral healthy leg. The limb symmetry index between the operated and the healthy leg was calculated.

The one-leg hop test was used for functional hop performance [7]. The best trial of each leg was chosen for statistical calculations. The limb symmetry index between the operated and the healthy leg was calculated.

Subjective measures/questionnaires

An anterior knee pain (AKP) score (0–50 points), modified from an earlier study and tailored for ACL-injured patients [27], was used to evaluate possible presence of AKP. The score consists of the following eight subgroups: pain, occurrence of pain, walking upstairs, walking downstairs, sitting with flexed knees >30 min, squatting, kneeling and arretations (catching). The maximum score is 50 points, which is equal to no AKP.

For self-reported knee-specific function, the Knee injury Osteoarthritis Outcome Score (KOOS) was used [29, 30]. KOOS consists of five separate subscales: Pain, other Symptoms, Function in Daily Living (ADL), Function in sport and recreation (Sport/Rec), and knee-related quality of life (Quality of life).

Type as well as level of physical activity (0–10 points) was collected by using The Tegner activity scale [37]. A high score means that the patient is able to participate in sports that place high demands on knee joint stability.

Postoperative ACL ruptures

During the 5-year follow-up period, the patients self-reported additional ACL injuries by either mail or telephone. Each patient was supported with medical care to have the diagnosis confirmed by clinical examination and either MRI or arthroscopy. The patients were then offered further treatment such as surgery followed by rehabilitation or non-operative treatment. The patients who did not report any additional ACL ruptures were either clinically examined at each follow-up or checked up for possible additional ACL injuries through the Swedish National ACL Register [35].

Statistical methods

Prior to the study, a power analysis based on anterior knee laxity was performed. A 1.5-mm side-to-side difference in anterior knee laxity of the operated knee estimated a sample size of 15 patients in each group with 80 % power at a significant level of $P \leq 0.05$. The power analysis was made as a "two-group repeated measures ANOVA" (Greenhouse–Geisser correction) with enquiry 4.0. Demographic data are presented in means and standard deviations or medians and lower and upper quartiles.

Using a 2 (treatment) × 3 (time: baseline, 2 and 5 year follow-up) design, clinical outcome regarding anterior knee laxity and limb symmetry index (LSI) of thigh muscle torque was analysed by applying a mixed linear model with fixed effects and relevant interactions. Mixed-model analyses allowed inclusion of subjects with missing data as well as uneven spacing between measurements [23]. These analyses included testing for graft choice, muscle torque of concentric and eccentric actions, a time effect, a time *x* graft interaction, and whether the ACL reconstruction was performed in the left or right knee. The analyses for anterior knee laxity included a covariance structure (compound symmetry). In situations in which a significant general treatment effect was observed, post hoc analysis using the Bonferroni method was used. SPSS version 20.0 was used for these analyses.

To analyse group differences based on the one-leg hop test and KOOS, the one-way ANOVA and post hoc comparisons were made according to the Tukey's honestly significant difference test. AKP as evaluated with the AKP score, the Tegner activity scale and the result of the pivot shift test were considered nonparametric data, and therefore, the Friedman's ANOVA followed by Mann–Whitney

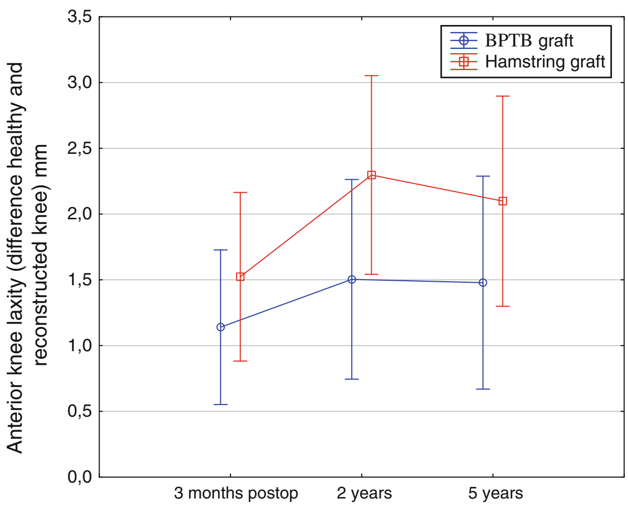

Fig. 1 Anterior knee laxity (mm) (Mean and 95 % CI) between the healthy and the operated knee 3 months, 2 and 5 years after ACL reconstruction with BPTB ($n = 34$) or hamstring graft/s ($n = 34$)

Table 2 Number (n) and percentage (%) of patients in the different grades of pivot shift (rotational knee joint stability), according to the IKDC classification (1 = none, 2 = + (glide), 3 = ++ (clunk), 4 = +++ (gross)

	3 months post-op	2 years post-op	5 years post-op
BPTB graft			
Subjects, *n*	32	30	27
Grade of pivot shift, *n* (%)	1:20 (62.5)	1:17 (57)	1:15 (55.5)
	2:11 (34.5)	2:10 (33)	2:11 (41.5)
	3:1 (3)	3:3 (10)	3:1 (4)
	4:-	–	4:-
Hamstring graft/s			
Subjects, *n*	30	29	26
Grade of pivot shift, *n* (%)	1:10 (33)	1:8 (27.5)	1:10 (38.5)
	2:18 (60)	2:13 (44.5)	2:12 (46)
	3:2 (7)	3:7 (24)	3:4 (15.5)
	4:-	4:1	4:-
P value[a]	0.05	0.02	n.s

[a] Kruskal–Wallis test for group differences between grafts

U test was used for statistical calculations. Statistica 10.0 was used for these analyses.

Results

Anterior knee laxity

No significant graft difference in anterior knee laxity was found at the 2- and 5-year follow-up (Fig. 1). No significant difference regarding anterior knee laxity was found

Table 3 Concentric/eccentric quadriceps and hamstring muscle torque over time at 90°/s for patients who have undergone ACL reconstruction with BPTB graft (*P*) or Hamstring graft/s (*H*)

	Pre-op	2 years post-op	5 years post-op
Quadriceps torque ratio (SE)			
P 90°/s concentric	0.90 (0.03)	0.94 (0.03) n.s	0.91 (0.03) n.s
H 90°/s concentric	0.90 (0.03)	0.91 (0.03) n.s	0.98 (0.03) n.s
P value (between grafts)	n.s	n.s	n.s
P 90°/s eccentric	0.88 (0.03)	0.90 (0.03) n.s	0.90 (0.03) n.s
H 90°/s eccentric	0.89 (0.03)	0.92 (0.03) n.s	0.96 (0.03) n.s
P value (between grafts)	n.s	n.s	n.s
Hamstring torque ratio (SE)			
P 90°/s concentric	0.90 (0.02)	0.99 (0.02)[††]	0.98 (0.02)[††]
H 90°/s concentric	0.92 (0.02)	0.88 (0.02) n.s	0.92 (0.02) n.s
P value (between grafts)	n.s	0.000	0.024
P 90°/s eccentric	0.88 (0.02)	0.99 (0.03)[††]	0.94 (0.03) n.s
H 90°/s eccentric	0.89 (0.02)	0.85 (0.03) n.s	0.89 (0.03) n.s
P value (between grafts)	n.s	0.000	n.s

Ratio between the operated and the healthy leg, standard error (SE) and level of significance are presented between and within groups

[†] Significantly higher values compared to preoperative values ($^{\dagger}P < 0.05$, $^{\dagger\dagger}P < 0.01$)

whether the ACL reconstruction was performed in the left or right knee.

Rotational knee joint stability

A significant graft difference in terms of rotational knee joint stability, in favour of the BPTB, was found at the 2-year follow-up ($P = 0.02$), but not at the 5-year follow-up (Table 2).

Thigh muscle torque at 90°/s

The leg symmetry values in muscle torque are presented in Table 3. No significant differences between and within grafts were found in concentric or eccentric quadriceps torque at either follow-ups.

A general treatment effect in terms of graft choice and ratio in concentric hamstring torque at 90°/s was found ($P = 0.001$). Post hoc tests revealed a significant graft difference in concentric hamstring torque at the 2-year follow-up, 0.99 (0.02) for BPTB compared to 0.88 (0.02) for hamstring graft ($P = 0.000$). No graft differences in concentric hamstring torque at 90°/s were shown at the 5-year follow-up.

A general treatment effect in terms of graft choice and ratio in eccentric hamstring torque at 90°/s was found ($P = 0.007$). Post hoc tests revealed a significant graft difference ($P = 0.000$) at the 2-year follow-up, 0.99 (0.02) for BPTB compared to 0.85 (0.03) for hamstring graft. No group differences in eccentric hamstring torque at 90°/s were found at the 5-year follow-up. Within group comparisons revealed that patients who had undergone ACL reconstruction with BPTB graft had significantly higher ($P = 0.01$) limb symmetry index in concentric, 0.99 (0.02), and eccentric, 0.99 (0.02), hamstring torque compared to preoperative values, 0.9 (0.02) at the 2-year follow-up and in concentric hamstring torque, 0.98 (0.02) at the 5-year follow-up ($P = 0.002$). No such significant difference was found in patients who had undergone ACL reconstruction with hamstring graft (Table 3).

Thigh muscle torque at 230°/s

No significant differences were found between or within groups in terms of graft choice and limb symmetry index in concentric and eccentric quadriceps muscle torque at 230°/s.

A general treatment effect in terms of graft choice and ratio in concentric hamstring torque at 230°/s was found ($P = 0.004$). Post hoc tests revealed a significant graft difference ($P = 0.000$) at the 2-year follow-up, 1.05 (0.02) for BPTB compared to 0.89 (0.02) for hamstring graft. No graft differences in concentric hamstring limb symmetry index at 230°/s were shown at the 5-year follow-up. No significant *within* group differences were found at the 5-year follow-up.

A general treatment effect in terms of graft choice and ratio in eccentric hamstring torque at 230°/s was found ($P = 0.04$). Post hoc tests revealed a significant ($P = 0.02$) graft difference at the 2-year follow-up, 1.01 (0.02) for BPTB compared to 0.88 (0.02) for hamstring graft. No group differences in eccentric hamstring torque at 230°/s were found at the 5-year follow-up. No significant within group differences were found at the 5-year follow-up (Table 4).

Functional hop performance

A significant ($P = 0.002$) group difference in hop length was found at the 2-year follow-up, 0.94 (0.07) for BPTB compared to 0.99 (0.07) for hamstring graft. No significant difference was found at the 5-year follow-up. Post hoc tests revealed a significantly decreased limb symmetry index, 0.99–0.94 for patients who had undergone ACL reconstruction with hamstring graft at the 5-year follow-up compared to the 2-year follow-up. For exact values and pairwise comparisons, see Table 5.

Table 4 Concentric/eccentric quadriceps and hamstring muscle torque over time at 230°/s for patients who have undergone ACL reconstruction with BPTB graft (*P*) or hamstring graft/s (*H*)

	Pre-op	2 years post-op	5 years post-op
Quadriceps torque ratio (SE)			
P 230°/s concentric	0.92 (0.02)	0.92 (0.01) n.s	0.89 (0.02) n.s
H 230°/s concentric	0.92 (0.02)	0.94 (0.03) n.s	0.95 (0.03) n.s
P value (between grafts)	n.s	n.s	n.s
P 230°/s eccentric	0.92 (0.03)	0.89 (0.01) n.s	0.94 (0.03) n.s
H 230°/s eccentric	0.93 (0.03)	0.93 (0.03) n.s	0.98 (0.04) n.s
P value (between grafts)	n.s	n.s	n.s
Hamstring torque ratio (SE)			
P 230°/s concentric	0.94 (0.03)	1.05 (0.02)[††]	0.98 (0.03) n.s
H 230°/s concentric	0.95 (0.02)	0.89 (0.02) *	0.94 (0.03) n.s
P value (between grafts)	n.s	0.000	n.s
P 230°/s eccentric	0.94 (0.03)	1.01 (0.02)[†]	0.95 (0.03) n.s
H 230°/s eccentric	0.89 (0.03)	0.88 (0.02) n.s	0.96 (0.03) n.s
P value (between grafts)	n.s	0.02	n.s

Ratio between the operated and the healthy leg, standard error (SE) and level of significance are presented between and within groups

* Significantly lower values compared to preoperative values (* $P < 0.05$)

[†] Significantly higher values compared to preoperative values ($^{\dagger}P < 0.05$, $^{\dagger\dagger}P < 0.01$)

Table 5 One-leg hop test for distance. Ratio between the operated and the healthy leg, confidence interval (CI), number of patients (*n*) and level of significance between patients who have undergone ACL reconstruction with BPTB or hamstring grafts are presented.

	2 years post-op	5 years post-op
BPTB graft	0.94 (0.07)	0.97 (0.08)
	$n = 28$	$n = 25$
Hamstring graft	0.99 (0.07)	0.94 (0.07)
	$n = 29$	$n = 21$
P value[a]	0.002	n.s

[a] One-way ANOVA test for group differences between grafts

Anterior knee pain

No significant graft differences in terms of AKP were found at the 2-year follow-up, 42 points (range 26–50) and 45.5 points (28–50), and at the 5 year follow-up, 45 points (range 17–50) and 45 points (range 25–50), for the patients who had undergone ACL reconstruction with BPTB and hamstring grafts, respectively.

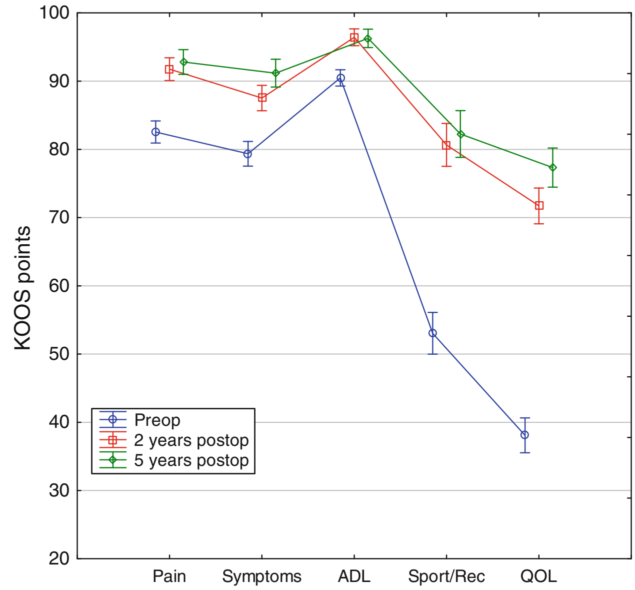

Fig. 2 Knee injury osteoarthritis outcome score (KOOS) scores (Mean and SE) for all included subjects in the subcategories pain, symptom, activity of daily living (ADL), sport/recreation (Sport/Rec) and quality of life (QOL) preoperatively ($n = 68$), 2 years ($n = 61$) and 5 years postoperatively ($n = 54$). Maximum score (100 points) means no knee-related problems

Knee function and quality of life

No significant group differences regarding knee function and quality of life, as determined with KOOS, were found over time in neither of the subscales of KOOS, and therefore, all patients were analysed together as one unit. A significant improvement ($P < 0.001$), irrespective of graft, was found over time in the subscales Sport/Rec, 53.0 points (SD 30.4) preoperatively, 80.6 points (21.6) 2 years postoperatively and 82.2 (SD 18.4) 5 years postoperatively and for quality of life 38.2 (SD 18.2) preoperatively, 71.7 (SD 21.7) 2 years postoperatively and 77.3 (21.6) 5 years postoperatively (Fig. 2).

Physical activity level

No significant graft differences in terms of level of physical activity were shown at the 5-year follow-up. A significant decreased activity level was found for all patients ($P \leq 0.001$), irrespective of graft, at the two-year 7 (1–10) and 5-year 7 (1–10) follow-up compared to pre-injury level of physical activity 7 (3–10).

Re- and contra lateral ACL ruptures

Over the five postoperative years, nine patients (13 %), one man and eight women, sustained a total of 11 (16.2 %) new ACL ruptures (BPTB graft = 4; hamstring graft, $n = 5$), seven (10.2 %) re-ruptures and four (5.9 %) ruptures of the contralateral leg.

Table 6 Patients, one male and eight females, who sustained additional ACL ruptures within 5 years after the primary ACL reconstruction, $n = 9$

Patient (sex)/graft	Re-rupture	Rupture contralateral knee
Male/BPTB	×	×
Female/hamstring	×	×
Female/BPTB	×	
Female/BPTB	×	
Female/hamstring	×	
Female/hamstring	×	
Female/hamstring	×	
Female/BPTB		×
Female/hamstring		×

Seven patients (10.2 %), one man and six women, sustained a re-rupture of the reconstructed ACL (BPTB graft, $n = 3$ and hamstring graft, $n = 4$). Of these seven patients, the man, who had undergone a primary ACL reconstruction with BPTB graft, and one woman, who had undergone a primary ACL reconstruction with hamstring graft, additionally sustained ACL ruptures of their contralateral leg. Two patients sustained ACL ruptures of their contralateral leg, one who had undergone a primary ACL reconstruction with BPTB graft and one with hamstring graft (Table 6).

Discussion

The principal findings of the present study were that no significant graft difference in anterior knee laxity was found at the 2- and 5-year follow-up. However, there was a significant difference in rotational knee joint stability in favour of the BPTB graft at the 2-year follow-ups. We found similar results for both grafts regarding quadriceps torque over time. In terms of hamstring torque, the between-graft comparisons differed significantly ($P = 0.000$) at the 2 year, 0.99 (0.02) for BPTB compared to 0.88 (0.02) for hamstring graft at 90°/s and 1.05 (0.02) for BPTB compared to 0.89 (0.02) for hamstring graft ($P = 0.000$) at 230°/s, but not at the 5-year follow-up. On a group level, none of the patients, irrespective of graft, returned to their pre-injury level of sports activity. Finally, eight out of nine patients who sustained an additional ACL rupture were women.

There is an on-going debate whether muscle strength of 90 % in the operated leg compared with the healthy leg is enough to be considered an optimal outcome [39]. Recently, it has been suggested that the muscle strength of the operated leg should be the same or even stronger than in the healthy leg [39], at least when it comes to so-called pivoting sports that put particularly high demands on knee joint stability [38]. Furthermore, comparisons with the healthy leg may not be fully appropriate since most patients are forced to give up physical exercise when ACL injured, leading to loss of muscle strength also of their healthy leg. This gives rise to a question of definition of optimal outcome. In the present investigation, thigh muscle torque was measured under non-fatigued conditions. It should be pointed out that Augustsson et al. [6] reported a higher side-to-side difference in favour of the healthy leg when they measured muscle torque during fatigued conditions 11 months after ACL reconstruction. Therefore, it is important to take into consideration that even if the analyses in the present study showed sufficient results in muscle torque measurements during non-fatigued conditions, the performance under fatigued conditions might be different.

It has been debated what test is most clinically relevant for the functional knee joint stability. The pivot shift test is suggested to be superior to the anterior drawer test [3]. In a recent laboratory study [16], using a model-based image-matching technique, the ACL injury mechanism was analysed. They found the knee joint to be in a valgus position and internally rotated when ruptured. This further stresses the importance of sufficient passive stabilisation in knee joint rotation. In the present study, the patients were evaluated every second month during the first postoperative year and they were rehabilitated at the same outpatient clinic performing the same rehabilitation type of exercises and training volume during the first three postoperative months. At the 7-month follow-up, there was a significant difference in anterior knee laxity and rotational knee joint stability in favour of patients operated on with BPTB graft compared to those with hamstring graft [14, 15]. At the 2-year follow-up, a graft difference in rotational knee joint stability was still present in favour of the BPTB graft [14, 15]. At the 5-year follow-up, no such difference was observed. The patients involved in the present study, with hamstring graft, are all operated on with the anterior single-bundle technique. The use of double-bundle techniques for ACL reconstruction with hamstring grafts has lately increased. Whether the results in the present study would have been different in involving patients who have undergone ACL reconstruction with double-bundle technique is unknown. However, Fujita et al. [11] found similar rate of negative pivot shift, when comparing double-bundle and anterior medial single-bundle technique.

Taking into consideration the incidence of new ACL ruptures in the present study, there were an equal number of ruptures in patients who have undergone BPTB and hamstring ACL reconstruction. However, it is remarkable that eight out of the nine patients with ACL re-ruptures were women. To our knowledge, there are no earlier studies present in the scientific literature to confirm this sex difference; instead, it has been reported that women are at a lower [21] or equal risk [31, 34] compared to men to sustain a re- or contralateral ACL rupture. One reason might be that women are more seldom return to pivoting sports crucial for sustaining a new ACL rupture to a lesser extent than men [e.g. 4, 5]. A second reason could be that most data on re- and contralateral ruptures consist of follow-up data of outcome after a primary ACL reconstruction that includes a lower number of women than men [12, 19, 36]. Since there are convincing data that women sustain primary ACL ruptures to a higher extent than men, one can further speculate whether this is true for re- and contralateral ruptures as well. In the present study, stratified for gender, an equal number of men and women were included, which might explain the high incidence of re-ruptures in women.

The ability of returning to sports after ACL reconstruction still remains controversial [4, 5, 11]. Returning to sports may put the athletic patient at risk for sustaining an additional ACL injury such as a re-rupture or a contralateral ACL injury. However, most authors suggest a 6-month rehabilitation programme before allowing the patient to return to sports. In the present study, on group level, neither the patients who had undergone ACL reconstruction with BPTB or hamstring grafts returned to their pre-injury level of sports activity at any point, including the 5-year follow-up. The reasons for not returning to the same level of sports activity in this cohort are unknown. Several reasons for this have been suggested in the literature, for example fear of re-injury correlating with low knee-related quality of life [4, 17], knee instability, pain [20] or high age [11]. Another reason might be at **what** time point after the ACL reconstruction the results were reported (i.e. meaning a slightly lower rate of return to sports when later than a 2-year follow-up) [4]. In the present study, the mean age of the patients was slightly higher, the study was stratified for gender and the percentage of women was also higher compared to earlier publications [12, 19, 36]. Those facts can probably only partly explain the results in terms of returning to sports activity. The significantly higher rotational knee joint instability in patients who had undergone ACL reconstruction with hamstring graft might also be a further explanation of the difference between grafts and returning to sports activity. In terms of knee-related quality of life measured with KOOS, the results of the present study and other studies [36] show that patients in general are not satisfied with either their quality of life or their impaired ability to perform sporting activities after ACL reconstruction. Hypothetically, the term 'optimal outcome' can be defined from different perspectives, for example from a patient's or from a society perspective, from a short- or long-term perspective, or from a more thematic view such as returning to sports activity, knee joint stability and knee function, as well as quality of life aspects [32, 41]. Månsson et al. [25] recently found that patients who had undergone ACL reconstruction rate their general health, social functioning and mental health higher and their physical functioning lower compared to a control group, measured with the SF-36.

One limitation in the present study might be the small number of patients. However, nine patients were excluded due to new ACL ruptures, and additionally, six patients were not able to undergo the 5-year follow-up due to a variety of reasons. The data analyses for muscle torque and anterior knee laxity were therefore performed with a so-called mixed-model analysis in order to secure that the data of the dropouts were included.

Conclusion

At the 5-year follow-up, there were no significant differences in terms of thigh muscle torques, knee joint stability, anterior knee pain, one-leg hop performance, quality of life or activity level, between patients who had undergone ACL reconstruction with a BPTB or a hamstring graft. However, none of the patients, irrespective of group belonging, returned to their pre-injury level of activity. Eight out of the nine patients who sustained a second ACL rupture were women.

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