Difference of Knee Strength Recovery Between Revision and Primary ACL Reconstruction

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ABSTRACT

Different grafting procedures are available to restore knee stability after revision anterior cruciate ligament (ACL) reconstruction. We compared knee strength recovery between ACL revision surgery and primary reconstruction. One hundred and ten patients with ACL revision surgery were matched with 110 patients with primary reconstruction based on the graft procedure. The isokinetic knee strength had been assessed for the first 9 months post-surgery. Knee laxity, function, and activity score were also evaluated. Limb symmetry index for knee extensor and flexor strength was not different at 4-, 6- and 9-months post-surgery between revision surgery and primary reconstruction. These results depended on ipsilateral or contralateral graft choice. Ipsilateral hamstring tendon (HT) and contralateral bone-patellar-tendon-bone (BPTB) graft procedures were similar for a revision of a BPTB graft failure. Contralateral HT procedure was better than ipsilateral BPTB procedure for a revision of a HT graft failure. The early recovery of isokinetic knee strength after ACL revision surgery regardless of the HT or BPTB procedures, was similar to the recovery after primary ACL reconstruction with the same graft technique. These results apparently depended on a temporary quadriceps arthrogenic muscle inhibition and on a persistent donor site morbidity, concerning the new and the previous grafts, respectively.

Introduction

There are more than 200,000 new cases of anterior cruciate ligament (ACL) injury per year in the United States [1]. This injury occurs especially during the practice of pivoting contact sports such as soccer or basketball, fighting sports such as Judo or Karate, and gymnastic or non-contact sports such as skiing or volleyball [2, 3]. To facilitate return to sports, many young athletes undergo surgical intervention to reconstruct the ACL [4]. In the United States, from 1994 to 2014, the incidence rate of ACL reconstruction increased from 30 to 75 per 100,000 person-year, particularly in young people under 20 and in people over 40 years old [1, 5, 6]. Patellar or hamstring grafts are often proposed to reconstruct the ACL, with good results in terms of knee laxity, isokinetic muscle strength recovery, knee pain and return-to-sport [7, 8]. However, a graft failure may occur after a new ipsilateral knee injury with a rate estimated from 4 to 11 % after return-to-play and from 7 to 16 % if the patients are under 25 [5, 9]. Graft failure is multifacto-

rial and most frequently depends on a technical issue, particularly because of tunnel mispositioning [10–12]. Young age (< 25 years), female gender, high body mass index, and return to a vigorous sport are identified as associated risk factors for an ACL revision [13–16]. The number of graft failures is not well known because the injured knee is not always unstable during daily life and some patients prefer to stop a risky sport rather than undergo a new knee surgery to return to sport. The number of ACL revisions is estimated from 2 to 4 % of ACL reconstructions [17–20]. Revisions of ACL reconstruction are unfortunately associated with lower clinical outcomes when compared with primary reconstructions, because of technical considerations and concomitant knee pathology as chondral lesions and meniscal deficiencies [21, 22]. The graft choice for revision ACL reconstruction is always discussed by surgeons so as to obtain the best result for their patients. The allograft needs a sterilization process and an irradiation, which may contribute to weakening the mechanical properties of the graft, but without the inconvenient of the donor site morbidity [22, 23]. The autograft is reasonable in athletes, depending on the graft used during the primary ACL reconstruction [22, 24]. If the initial procedure was a hamstring autograft (HT), the revision is possible using an ipsilateral bone-patellar-bone autograft (BPTB) or a contralateral hamstring graft [22, 25]. Likewise, if the initial procedure was a BPTB autograft, the revision is possible using a contralateral BPTB autograft or a contralateral hamstring graft. The delay in return to sport may be longer after ACL revision and will depend on the patient's ability to regain symmetric strength to complete a series of sport-specific tests [22]. After primary ACL reconstruction the full recovery of the knee strength might in some cases require up to 24 months [26, 27]. A knee flexors deficit is measured after the hamstring procedure, and an extensors deficit is measured after the bone-patellar-tendon-bone procedure [26, 27]. However, muscle strength recovery has not been properly studied after revision of ACL reconstruction [28]. Indeed, recovery of muscle strength may be more difficult following ACLR revisions due to the knee damage occurring during the tendon graft rupture responsible for a new knee laxity and instability. The primary objective of this study was therefore to assess the isokinetic knee extensor and flexor strength of patients who underwent an ACLR revision surgery over a 9-month period to determine if muscle strength recovery, defined as muscle strength symmetry, was similar after revision of ACL reconstruction compared to a paired primary ACL reconstruction. The secondary objectives were i) to compare the ipsilateral hamstring tendon procedure with the contralateral BTPB procedure in cases of bone-patellar-tendon-bone procedure revision, and ii) to compare the ipsilateral bone-patellar-tendon-bone procedure with the contralateral hamstring tendon procedure in cases of hamstring tendon procedure revision.

Materials and Methods

Population

The patients studied were selected in a retrospective cohort over a period extending from January 2010 to December 2019. As far as the ACL revision group was concerned, the patients were selected according to the following criteria: i) one stage revision ACL reconstruction with contralateral HT or ipsilateral BPTB, if the primary ACL surgery had used an HT graft, ii) one stage revision ACL reconstruction with contralateral BPTB or ipsilateral HT graft, if the primary ACL surgery had used an BPTB graft, and iii) isokinetic knee strength follow-up performed at 4, 6 and 9 months post-surgery. Revision ACL reconstruction with allograft, quadriceps tendon graft or other tendon grafts were excluded because these types of procedures could not be compared with a primary ACL reconstruction. Multi-ligament procedures and realignment osteotomies were also excluded. The study also excluded patients who had experienced recurrent knee instability during the follow-up, despite the revision ACL reconstruction, and patients who had not had two or more isokinetic evaluations over the 9-month postoperative period.

The patients with primary ACL reconstruction were selected in a retrospective cohort set up between 2005 and 2019. This cohort included 953 patients and followed knee isokinetic strength after primary HT or BPTB ACL reconstructions.

Patients with revision of ACL reconstruction were matched with primary ACL reconstruction patients according to sex, age (± 2 years), weight (± 2 kg) and height (± 2 cm) in order to compare them based on the type of grafts. The sports activities were collected even though this parameter could not be used for data matching, because too many different sports had been practiced before the ACL rupture; in addition, the initial sport was not always the same one when the rupture of the graft occurred. Similarly, matching depending on the surgeon was not possible due to a cohort of patients operated on by several surgeons specializing in knee surgery and working in different public or private hospitals. During the follow-up, knee pain and post-operative complications were collected because of their link with knee strength recovery after ACL reconstruction [29].

All the patients gave their written consent to be involved in the study without any financial retribution, and the isokinetic evaluation protocol corresponded to the usual clinical follow-up of ACL reconstructions. The study protocol had been approved by the Institutional Ethic Committee.

Standardized follow-up after ACL reconstruction

All the patients had an individual and "accelerated" rehabilitation program originally described by Shelbourne et al. in 1992 for the BPTB procedure and by De Carlo et al. for the hamstring procedure in 1994 [30, 31]. These programs started on the day after surgery, they consisted of encouragement for full active knee extension and full range of motion, fast quadriceps activation depending on knee swelling, and early weight bearing as soon as possible, with and without crutches [30–33]. These rehabilitation programs were supervised by a physiotherapist for an average of 40 outpatient sessions or for 30 inpatient sessions (3 weeks with 2 sessions per day) followed by 10 out-patient sessions, depending on the choice of the patients. At 2 months post-surgery, patients were authorized to start cycling by the surgeon only if the knee was stable and painless, and had full range of motion without swelling. At 4 months post-surgery, isokinetic knee strength, functional and activity scales were assessed by a sports medicine physician to encourage running, if the same pre-cited clinical parameters had been reached and if the recovery of the isokinetic quadriceps strength was superior to 40 % (limb symmetry index (LSI) > 60 %, which is calculated

as follow: peak torque of ACL reconstruction side / peak torque of contralateral knee side) x 100) to those of the contralateral knee [26, 34]. When the isokinetic quadriceps LSI was between 50 and 60 %, the continuation of cycling was proposed. Above 50 % knee rest was requested with stretching of the knee muscle and practice of swimming. At 6-month post-surgery, the same clinical and isokinetic evaluation was performed and completed by a hop-test to determine whether sports without pivot movements could be authorized. After 9 months post-surgery, clinical examination, isokinetic knee strength and hop-tests were assessed again, especially in patients with primary or revision of ACL reconstruction who wanted to return to competitive sports.

Isokinetic procedure

After a 10-minute cyclo-ergometer warm-up, isokinetic strength tests were performed using a Humac Norm dynamometer (CSMI-Medimex, Ste Foy les Lyon, France). Each subject was seated with a hip angle of 85 degrees. The mechanical axis of the dynamometer was aligned with the lateral epicondyle of the knee. The trunk and the thigh were stabilized with belts. The knee range of motion (ROM) was 100 degrees (100 ° to 0 ° = full knee extension). Torque was gravity-corrected, and the dynamometer recalibration was performed monthly according to the manufacturer's instructions. All the evaluation tests were conducted by the same physician specializing in sports medicine. The two knees were evaluated, beginning with the non-reconstructed knee side after instruction, as well as verbal encouragements and visual feedback. After familiarization with the isokinetic movement, the patients were tested over three repetitions of concentric knee extension and flexion at 60 °/s followed by five concentric repetitions at 180 °/s [35]. Thirty seconds of rest were provided between the two series and 2 minutes between the two sides.

The judgment criteria were the quadriceps and hamstring limb symmetry index (LSI), calculated at 60 and 180 °/s for the revision ACL reconstruction group according to the following formula: (Peak torque of Revision ACL reconstruction side / Peak torque of contralateral knee side) x 100. The formula: (Peak torque of Primary ACL reconstruction side / Peak torque of contralateral knee side) x 100 was used for the primary ACL reconstruction group. The reliability of quadriceps and hamstring LSI reported previously in literature at 60 and 180 °/s are acceptable (ICCs: 0.43 to 0.78) [36].

Knee laxity

Knee laxity was measured in millimeters by the same physician at 9 months post-surgery using a KT-1000 arthrometer (MEDmetric Corp., San Diego, CA, USA) at 134 Newtons. The intra-examiner reliability of the knee laxity measurements is good for 134 Newtons [37]. A Lachman test was also performed. The Lachman test < 5 mm of anterior displacement compared to the opposite side indicates a negative test [38].

Functional parameter

Single leg hop distance was measured at 6 and 9 months after ACL reconstruction because this test is usually incorporated in the return to sport criteria after knee surgery [39]. The LSI was calculated according to the formula: (Hop distance of the reconstructed knee / Hop distance of the contralateral knee side) x 100 [40]. The reliability of the hop LSI is good (ICCs: 0.92) with a greater change on the operative limb [41].

Activity scales

The Lysholm scale was used to evaluate functional impairment due to the knee symptoms during activity [42]. This scale of 100 points is considered from good to excellent for a scale between 84 and 100 points. The Tegner activity scale was used complementary to the Lysholm functional scale to evaluate the level of work and sports activities [43]. This score was assessed during the patient's medical interview in order to know the activity level before the ACL rupture, and then during the follow-up, assessed at 4, 6 and 9 months post-surgery. The Tegner activity scale is a one-item score which grades the activity on a scale from 0 to 10. Level 3 represents a work-light labor like nursing or sport-swimming or walking in forest and level 10 represents a competitive sport such as soccer practiced at a national or international level.

Statistical analysis

Statistical analysis was performed using the SPSS 23.0 software (Armonk, NY, USA). The quantitative variables were expressed in mean and standard-deviation. The categorical variables were expressed in median, maximum, minimum or frequency. The normal distribution of groups and sub-groups was verified with a Shapiro-Wilk test. First, the comparison between revision and primary ACL reconstruction groups was assessed by a paired t-test and a McNemar χ^2 test. Second, sub-groups according to the type of graft were compared using one-way ANOVA (6 groups x quantitative parameter) followed by a Bonferroni or a Dunnet post-hoc test based on the variance homoscedasticity. Results were considered significant at $p < 0.05$.

Results

One hundred and ten patients with revision ACL reconstruction, 31 women (28,2 %) and 79 men (71,8 %) were included. The graft failure was determined clinically by a surgeon, and confirmed by MRI, after a non-contact sports mechanism for 75 patients out of 110 (68 %) who presented knee instability. Patient age with revision ACL reconstruction was 25.8 ± 6.6 years and the median of delay between primary and revision ACL reconstruction was 60 months (6 to 240 months). The duration between graft failure and the revision surgery of ACL reconstruction was 294 ± 514 days (▶ **Table 1**). The type of revised ACL reconstruction depended on the primary ACL procedure and on the surgeons' choices according to their habits to harvest ipsi- or contralateral knee tendon(s) for performing a new graft. Sixty-six primary ACL reconstructions were revised with HT grafts and compared to 66 primary ACL reconstructions with HT grafts. Contralateral HT graft was used in 16 cases. Forty-four primary ACL reconstructions were revised using BPTB graft and compared to 44 primary ACL reconstructions with BPTB graft. Contralateral BPTB graft was used in 13 cases.

In case of meniscal injury, suture or ablation were associated, depending on the type of injury, with the ACL reconstruction or revision. Fifty-nine meniscal procedures were associated to the revision ACL reconstruction (▶ **Table 1**).

▶ **Table 1** Characteristics and follow-up of revision and primary ACL reconstruction groups.

	Revision ACL reconstruction (n = 110)	**Primary ACL reconstruction (n = 110)**	***p***
Age (year)	25.8 ± 6.6	25.9 ± 6.3	0.86
Weight (kg)	72.9 ± 11.6	72.8 ± 11.6	0.95
Height (cm)	170 ± 21	169 ± 19	0.88
Isokinetic follow-up (day):			
1st evaluation (4 months)	128 ± 37	121 ± 14	0.21
2nd evaluation (6 months)	187 ± 18	188 ± 16	0.79
3rd evaluation* (9 months)	262 ± 46	252 ± 27	0.29
Reconstruction side:			
Right knee	61 (55.5 %)	64 (58.2 %)	0.68
Left knee	49 (44.5 %)	46 (41.8 %)	
Sport before ACL reconstruction:			
Soccer	43 (39.1 %) [a]	60 (54.5 %) [a]	**0.02**
Basketball	14 (12.7 %)	17 (15.6 %)	
Handball	10 (9.1 %)	11 (10 %)	
Rugby	8 (7.3 %)	5 (4.5 %)	
Fight Sport	5 (4.5 %)	3 (2.7 %)	
Other sport	30 (27.3 %)	14 (12.7 %)	
Meniscus procedure:			
CM	36	29	0.39
LM	17	21	
CM + LM	6	6	
Post-operative complications:			
No	68 (61.9 %)	70 (63.7 %)	0.12
Swelling	11 (10.1 %)	2 (1.8 %)	
Anterior Knee Pain	15 (13.5 %)	20 (18.1 %)	
Posterior Knee Pain	6 (4.4 %)	8 (7.3 %)	
Arthrofibrosis	11 (10.1 %)	10 (9.1 %)	
Post-operative rehabilitation:			
Inpatient	75 (68.2 %)	61 (55 %)	0.052
Outpatient	35 (31.8 %)	49 (45 %)	
Activity at 4 months follow-up:			
Rest	22 (20 %)	10 (9.1 %)	**<0.01**
Cycling	59 (53.7 %) [a]	29 (26.4 %) [a]	
Running	7 (6.3 %) [a]	70 (63.6 %) [a]	
Unknown	22 (20 %)	1 (0.9 %)	

*n = 91 patients in each group; [a] significant difference between revision and primary ACL reconstruction.

The various sports practiced before ACL reconstruction are listed in ▶ **Table 1**, where soccer was the most practiced sport before graft failure (39 % of cases). Ninety-one revision ACL reconstruction patients (82 %) intended to return to their previous sport. Yet only 38 out of them (42 %) still maintained their goal at 9 months post-surgery after the isokinetic evaluation. The others no longer had the wish to return to their previous sport.

Comparison between revision and paired primary ACL reconstruction

After matching method, the duration between ACL tear and the primary ACL reconstruction and the duration between graft failure and the ACL revision were not different (223 ± 348 vs. 294 ± 514 days; p = 0.28) and the isokinetic follow-up was comparable (▶ **Table 1**).

The revision and primary ACL reconstruction groups were not different concerning the association with a meniscal procedure and the occurrence of knee pain complications (▶ **Table 1**). A trend for more inpatient rehabilitation was present after revision ACL reconstruction (p = 0.052) (▶ **Table 1**). More patients with revision ACL reconstruction chose to practice cycling between 4 to 6 months post-surgery compared to patients with primary ACL reconstruction who returned to running more frequently at 4 months post-surgery (p < 0.01) (▶ **Table 1**).

The extensors and flexors knee strength deficits expressed in LSI were not different between revision and primary ACL reconstruction (▶ **Table 2**). At 4-, 6- and 9-months post-surgery, the extensors isokinetic strength LSI at 60 °/s were, respectively, 67 ± 21, 78 ± 19 and 84 ± 26 % for revision ACL reconstruction group and were, respectively, 66 ± 16, 80 ± 11, and 84 ± 14 % for the primary ACL reconstruction group (p = 0.63, p = 0.55, and p = 0.20, respectively). During the same follow-up, the flexors isokinetic strength LSI at 60 °/s were, respectively, 86 ± 17, 93 ± 25 and 87 ± 16 % for revision ACL reconstruction group, and were, respectively, 86 ± 14, 94 ± 13 and 92 ± 12 % for the primary ACL reconstruction group (p = 0.96, p = 0.66, and p = 0.31).

No difference was found between revision and primary ACL reconstruction for the hop-test at 6 (95 ± 2 % vs. 89 ± 4 %; p = 0.13) and 9 months post-surgery (94 ± 8 % vs. 90 ± 8 %; p = 0.23) and for the knee laxity at 9 months post-surgery (p = 0.78) (▶ **Table 2**). The Lysholm score was only significantly lower in the revision ACL reconstruction group at 4 months post-surgery, but with a mean of 92 points, already corresponding to a good result (▶ **Table 2**). The level of sports activity recovery assessed by the Tegner activity scale was comparable between the two groups during the post-operative follow-up (▶ **Table 2**).

Comparisons according to the choice of graft

Ipsilateral HT or contralateral BPTB procedures after a Bone-Patellar-Tendon-Bone graft failure

The recovery of the extensors and flexors strength was not different between ipsilateral HT or contralateral BPTB procedures at 4-, 6- and 9-months post-surgery (▶ **Table 3**). The hop-test and the Lysholm scores were comparable during the same follow-up (▶ **Table 3**). Only the Tegner scale was 1 point lower at 4 months post-surgery in case of contralateral BPTB procedure (▶ **Table 4**). In case of ipsilateral HT, knee strength recovery was comparable to that of a primary HT ACL reconstruction (▶ **Table 3**). In case of contralateral BPTB, the extensors strength deficit was significantly lower than that measured at 4 months post-surgery after a primary BPTB reconstruction (LSI at 60 °/s: 80 ± 26 vs. 61 ± 15 %, respectively; p < 0.05). So, groups were different at 4 months post-surgery, but were comparable at 6 months (LSI at 60 °/s: 80 ± 23 vs. 74 ± 13 %, respectively; p > 0.05) and 9 months (LSI at 60 °/s: 95 ± 26

▶ **Table 2** Comparison of isokinetic knee strength recovery, Lysholm score, hop-test LSI and Tegner activity scale between revision and paired primary ACL reconstruction at 4, 6 and 9 months post-surgery.

Post-operative follow-up	Revision ACL reconstruction	Primary ACL reconstruction	*p*
4 months:			
E60 LSI (%)	67 ± 21	66 ± 16	0.63
E180 LSI (%)	78 ± 24	76 ± 21	0.73
F60 LSI (%)	86 ± 17	86 ± 14	0.96
F180 LSI (%)	91 ± 19	90 ± 16	0.96
6 months:			
E60 LSI (%)	78 ± 19	80 ± 11	0.55
E180 LSI (%)	84 ± 16	85 ± 11	0.80
F60 LSI (%)	93 ± 25	94 ± 13	0.66
F180 LSI (%)	95 ± 25	96 ± 15	0.69
9 months:			
E60 LSI (%)	84 ± 26	84 ± 14	0.20
E180 LSI (%)	85 ± 17	81 ± 13	0.35
F60 LSI (%)	87 ± 16	92 ± 12	0.31
F180 LSI (%)	90 ± 19	95 ± 13	0.21
Lysholm score:			
4 months post-surgery	92 ± 10	95 ± 8	**0.02**
6 months post-surgery	93 ± 8	98 ± 4	0.07
9 months post-surgery	93 ± 10	97 ± 6	0.24
Tegner activity scale:			
Before ACL tear or graft failure	7 [4–10]	7 [5–10]	0.51
4 months post-surgery	4 [3–6]	4 [3–6]	0.62
6 months post-surgery	4 [3–8]	4 [3–7]	0.68
9 months post-surgery	5 [3–8]	5 [3–10]	0.67
Hop-test LSI (%):			
6 months post-surgery (n = 51)	95 ± 2	89 ± 4	0.13
9 months post-surgery (n = 41)	94 ± 8	90 ± 8	0.23
Side-to-side knee laxity (mm):			
9 months post-surgery (n = 41)	2.5 ± 2.4	2.1 ± 2.2	0.78

Abbreviations: LSI: Limb Symmetry index; E60 LSI: Limb Symmetry index of knee extensors at 60 °/s; F180 LSI: Limb Symmetry index of knee flexors at 60 °/s.

vs. 81 ± 15 %, respectively; p > 0.05) post-surgery after BPTB graft failure.

Ipsilateral BPTB procedure or contralateral HT procedure after a hamstring tendon graft failure

The extensors strength recovery after ipsilateral BPTB procedure was lower than that observed after contralateral HT (LSI at 60 °/s: 56 vs. 76 % at 4 months; 71 vs. 87 % at 6 months and 76 vs. 90 % at 9 months, respectively) (▶ **Table 3**). The flexors strength was symmetric during the follow-up after contralateral HT procedure. The hop-test, the Lysholm score and the Tegner scale were comparable during the same follow-up (▶ **Table 3** and ▶ **4**).

In case of ipsilateral BPTB procedure, the flexors strength deficit tended to be higher compared to a primary BPTB procedure, and in case of contralateral HT procedure, the flexors strength deficit tended to be lower compared to a primary HT procedure.

So, contralateral HT procedure presented better knee strength recovery than ipsilateral BPTB procedure during the first nine months post-surgery after a HT graft failure.

Discussion

Revision ACL reconstruction is a technical challenge that aims to obtain at least a functional and stable knee for daily life activities [22]. Yet some young patients want to return to competitive sports that are risky for their knees [44]. So the challenge is to recover the knee strength symmetry essential for the general function, as well as a healthy knee for a return to sport [27]. However, only a few studies have measured muscle strength recovery with an isokinetic dynamometer or a similar device after revision of ACL reconstructions [38]. There are various grafts used for revision ACL reconstruction, and the groups of patients are therefore difficult to study [45]. Only case series and case controls studies have reported muscle strength deficiency after revision ACL reconstruction using autograft [28, 38, 45–47].

After a follow-up superior to 42 months, when ipsilateral BPTB graft was used for ACL revision using BPTB harvesting, the literature shows that the extensors strength and the flexors strength LSI at 60 °/s ranged from 82 to 103 % and from 88 to 96 %, respectively [45–47]. These results were comparable to those reported by Dauty et al. in 2014 from a 12-month post-surgery follow-up (88 and 94 %, respectively) for the ipsilateral BPTB procedure after primary hamstring graft [28]. Our current results were lower (76 and 88 %), perhaps because a 9-month post-surgery follow-up was too short a delay to recover full knee strength as part of a complete recovery.

After pairing method, based on the type of graft, the extensors strength and the flexors strength LSI at 4, 6 and 9 months were similar between revisions and primary ACL reconstructions. Gifstad et al. found the same results at 90 months of follow-up between 56 ACL revisions (31 BPTB and 25 HT grafts) and an unmatched control group of primary ACL reconstructions (44 BPTP and 8 HT grafts) [38]. Our current results were 5 % lower (84 and 87 %); this is possibly because a 9-month post-surgical follow-up may be insufficient to assess a complete recovery of knee strength compared to the 90-month follow-up described by Gifstad et al. Yet the originality of our study was to show the difference of recovery during the first month post-surgery based on the type of grafts used for the revision ACL reconstruction. To explain knee strength LSI during the first 9 months after ACL reconstruction and revision, two hypotheses can be made. First, the arthrogenic muscle inhibition (AMI), which predominated on the knee extensors (quadriceps) of the operated knee, depends on the post-operative knee effusion [48–50]. When joint effusion was experimentally induced by intraarticular infusion of physiological saline into the knee (30 to 60 ml), vastus medialis and lateralis muscle activity decreased [48]. After knee joint aspiration, an increase of isometric knee extensor torque and muscle electromyographic activity was reported [49], without any evidence of a supraspinal contribution to quadriceps AMI [50]. Second, the donor site morbidity may cause a lasting strength deficit for more than 24 months on the knee extensors in case of BPTB

▶ **Table 3** Isokinetic knee strength recovery, Lysholm scale and hop-test at 4, 6 and 9 months based on the graft procedures (ANOVA).

	BPTB by HTi	BPTB by BTPBc	Paired primary BPTB	Paired primary HT	HT by HTc	HT by BPTBi
Graft or ACL rupture-surgery delay (day)	309 ± 595	391 ± 837	242 ± 415 *	213 ± 275 *	206 ± 311	202 ± 175
Follow-up						
4 month (day)	120 ± 13	116 ± 27	122 ± 13	120 ± 16	118 ± 17	129 ± 11
6 months (day)	188 ± 17	177 ± 21	186 ± 16	182 ± 19	184 ± 20	189 ± 16
9 months (day)	251 ± 49	248 ± 30	255 ± 32	260 ± 36	269 ± 62	268 ± 51
Lysholm scale						
4 months	94 ± 9	86 ± 14 [a]	94 ± 8	95 ± 7 [a,b]	94 ± 9	87 ± 10 [b]
6 months	98 ± 6	98 ± 3	97 ± 6	98 ± 4	96 ± 7	96 ± 8
9 months	96 ± 3	96 ± 3	96 ± 6	96 ± 7	93 ± 11	96 ± 8
Hop-test (%)						
6 months	93 ± 3	95 ± 5	94 ± 8	91 ± 5	95 ± 2	92 ± 6
9 months	92 ± 1	94 ± 2	92 ± 6	92 ± 7	92 ± 4	92 ± 5
Isokinetic testing						
4 months						
E60 LSI (%)	71 ± 18 [g]	80 ± 26 [f]	61 ± 15 [e,f,g]	69 ± 16 [b,c]	76 ± 21 [c,d,e]	56 ± 17 [b,d]
E180 LSI (%)	80 ± 27 [g]	89 ± 22 [f]	74 ± 24 [f,g]	77 ± 15 [b,c]	81 ± 18 [c]	69 ± 17 [b]
F60 LSI (%)	82 ± 14 [g,i]	84 ± 9	92 ± 13 [g,h]	81 ± 13 [c,h]	101 ± 19 [c,d,i]	83 ± 16 [d]
F180 LSI (%)	85 ± 13 [g,i]	93 ± 17	99 ± 14 [g,h]	82 ± 14 [c,h]	104 ± 26 [c,d,i]	90 ± 17 [d]
6 months						
E60 LSI (%)	81 ± 13	80 ± 23	74 ± 13 [e,h]	87 ± 16 [b,h]	87 ± 19 [e]	71 ± 18 [b]
E180 LSI (%)	81 ± 13	81 ± 23	74 ± 20 [e,h]	88 ± 16 [b,h]	88 ± 18 [e]	72 ± 17 [b]
F60 LSI (%)	91 ± 32	88 ± 12	96 ± 12 [g,h]	87 ± 12 [h]	97 ± 19	90 ± 18
F180 LSI (%)	84 ± 13 [g,i]	95 ± 11	100 ± 12 [g,h]	87 ± 15 [c,h]	102 ± 17 [c,i]	94 ± 14
9 months						
E60 LSI (%)	85 ± 20	95 ± 26 [f,k]	81 ± 15 [f]	88 ± 18	90 ± 12	76 ± 15 [k]
E180 LSI (%)	85 ± 11	93 ± 27	83 ± 14	89 ± 15	88 ± 18	81 ± 12
F60 LSI (%)	89 ± 19	96 ± 16	99 ± 9 [h]	85 ± 12 [c,h]	101 ± 20 [c]	88 ± 15
F180 LSI (%)	85 ± 21 [g,i]	100 ± 13	103 ± 12 [g,h]	85 ± 16 [c,h]	105 ± 22 [c,i]	94 ± 17

[a] Significant difference between HT primary and HT by BPTBi; [b] Significant difference between HT primary and BPTB by BPTBc; [c] Significant difference between HT primary and HT by HTc; [d] Significant difference between HT by HTc and HT by BPTBi; [e] Significant difference between BPTB primary and HT by HTc; [f] Significant difference between BPTB primary and BPTB by BPTBc; [g] Significant difference between BPTB primary and BPTB by HTi; [h] Significant difference between HT primary and BPTB paired primary; [i] Significant difference between HT by HTc and BPTB by HTi; [j] Significant difference between HT by HTc and BPTB by BPTBc; [k] Significant difference between HT by BPTBi and BPTB by BPTBc *Significant difference between Primary ACL reconstructions (p-value < 0.05).

▶ **Table 4** Tegner activity scale before ACL or graft rupture during the 4 to 9 months follow-up based on the graft procedures (ANOVA).

	BPTB by HTi	BPTB by BTPBc	Primary BPTB	Primary HT	HT by HTc	HT by BPTBi
Before ACL injury	7 [5–10]	7 [5–10]	7 [5–9]	7 [5–10]	8 [6–10]	7 [5–10]
4 months post-surgery	4 [3–6] [a]	3 [3,4] [a,b]	4 [3–5]	4 [3–6] [b]	4 [3–5]	4 [3–5]
6 months post-surgery	4 [3–6]	4 [3–6]	4 [3–6]	4 [3–7]	4 [3–5]	4 [3–5]
9 months post-surgery	5 [4–8]	5 [4–7]	5 [4–8]	5 [4–9]	5 [5–7]	5 [4–7]

[a] Significant difference between BPTB by BPTBc and BPTB by HTi; [b] Significant difference between BPTB by BPTBc and Primary HT procedure.

graft or on the knee flexors in case of HT graft [27, 51]. The muscle tendon properties of the semitendinosus and the gracilis muscles were reported substantially altered in 65 % of the cases after harvesting, and these alterations contributed to a knee flexor weakness on the surgical limb [51]. In 1995, Yasuda et al. had already shown this phenomenon when they studied the knee flexors strength after primary ACL reconstruction with ipsilateral or contralateral HT [52]. A decreased flexors muscle strength was reported 9 months after surgery on the harvest knee side. In the same way in 2000, Shelbourne et al. had shown that the quadriceps muscle strength was greater in the primary reconstructed knee at 1, 2

and 4 months after contralateral BPTB procedure compared to ipsilateral BPTB procedure [53].

The authors concluded that the use of the contralateral patellar tendon could help restore more quickly strength symmetry than the ipsilateral patellar tendon graft. The return to full capacity in sport was faster without compromising ultimate stability [53]. Moreover, the consequences on the donor site after the first ACL reconstruction could last for a long time after surgery [28]. Indeed, that may occur when the same ACL reconstruction technique is chosen using the contralateral tendon of the primary ACL reconstruction. Symmetrical knee strength may also be easier to obtain because of a previous strength deficit due to the primary ACL reconstruction, which may be comparable to the strength deficit secondary to revision procedure.

According to our results, after BPTB graft failure, the revision ACL reconstruction with ipsilateral HT graft causes a low extensors strength deficit due perhaps to the quadriceps AMI and a high and lasting flexors strength deficit in the reconstructed knee side equivalent to a primary HT graft procedure. If a contralateral BPTB graft is chosen, a quadriceps AMI explains the extensors strength deficit on the reconstructed knee side and the contralateral patellar tendon graft accounts for an extensors strength deficit in the none-reconstructed knee side. The extensors strength symmetry is also easier to obtain, and no flexors strength deficit is present.

After HT graft failure, the revision ACL reconstruction with ipsilateral BPTB graft causes a high extensors strength deficit due to the quadriceps AMI and to the new patellar tendon ipsilateral donor site morbidity on the reconstructed knee side. A flexor strength deficit of 10 % or more is often present because of the previous HT graft procedure [28]. If a contralateral HT graft is chosen, a quadriceps AMI accounts for a low extensor strength deficit on the reconstructed knee side and a lasting flexor strength deficit on the non-reconstructed knee side. The flexor strength symmetry is also easier to obtain if a previous flexor strength deficit is present on the reconstructed knee side because of the previous morbidity of the primary HT graft.

The rehabilitation program apparently did not have any influence on knee strength recovery even if the groups were not matched according to this specific parameter. Rousseau et al. have already shown that inpatient and outpatient rehabilitations were similar in terms of knee strength recovery after primary ACL reconstruction [54]. Moreover, rehabilitation exercises remained necessary in the event of knee pain complications after ACL reconstruction. Likewise, aerobic physical activities performed between 4 to 6 months after ACL reconstruction did not improve knee strength recovery [55]. Furthermore, it seems likely that patients, who had undergone two surgeries on the same knee, might have reconsidered their athletic ambitions. Thus, the knee was not negatively impacted by a highly intensive rehabilitation program, which is often responsible for greater deficits in isokinetic strength because of overloaded adaptation capacities of the operated knee [29]. Most of the time, patients think that only exercises improve knee strength, while the absence of complications is a major factor in the normalization of side-to-side knee strength.

This study has some limitations because of the low number of patients in the sub-groups, especially for the revision ACL reconstruction group using contralateral graft. In fact, the indication for the use a contralateral graft is not clear and depends on the personal habits and experience of the surgeon who may prefer HT or BPTB grafts because they are two comfortable routine procedures [56, 57]. The contralateral procedure is not common, perhaps due to fear of damaging the healthy knee [25]. Because of the small number of revision ACL reconstructions using contralateral graft, new studies including more cases are necessary to obtain more reliable results. The short follow-up of 9 months corresponds to a second limitation because full knee strength may not be fully recovered at this endpoint. This limitation can be explained by our local habits which proposed only isokinetic testing if the patients with revision ACL reconstruction wanted to return to a competitive sport. Although 91 patients with revision ACL reconstruction (82 %) intended to return to their sport before surgery, only 38 out of them (42 %) maintained their goal at 9 months post-surgery after the isokinetic evaluation. Yet we can consider that only a 5 % strength increase could have been expected on the reconstructed knee, if the postoperative follow-up had been prolonged for more than 24 months, according to the results of literature [38]. Another limit is the lack of exact knowledge regarding the degenerative state of the operated knee, such as early osteoarthritis lesions, which were not assessed in this study. However, the knee strength recovery being similar to that of the primary ACL reconstruction seems to show that the early knee strength recovery might not be linked to the presence or absence of degenerative lesions. The impact of knee pain on knee strength recovery was not due to a limited sample size, even if the number of pain complications was similar in the revision group and in the paired primary ACL reconstruction group. More studies with a large sample will help validate these findings after making adjustments for these potential covariates.

Finally, our results cannot be applied to other grafts such as quadriceps or other tendon grafts or allografts, for example. Indeed, as their characteristics are different, their consequences in terms of early knee strength recovery would undoubtedly be different.

Conclusion

According to the concept of the knee strength symmetry recovery, results after revision ACL reconstruction were similar to those measured after primary ACL reconstruction using the same technique. Based on this parameter, after BPTB graft failure, ipsilateral HT procedure or contralateral BPTB procedure could be chosen indifferently, although many other criteria must be considered. After HT graft failure, the contralateral HT procedure was better than the ipsilateral BPTB procedure, but only for the first 6 months post-surgery. These results seemed to depend on a non-lasting quadriceps arthrogenic muscle inhibition and on a lasting donor site morbidity, potentially concerning the previous graft and the new graft. Finally, this isokinetic knee strength recovery was relevant for the short follow-up of revision ACL reconstructions when discussing the possibility of returning to a sport.

Conflict of Interest

The authors declare that they have no conflict of interest.

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