Anterolateral Ligament Reconstruction Is Associated With Significantly Reduced ACL Graft Rupture Rates at a Minimum Follow-up of 2 Years

A Prospective Comparative Study of 502 Patients From the SANTI Study Group

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Background: Graft failure and low rates of return to sport are major concerns after anterior cruciate ligament (ACL) reconstruction, particularly in a population at risk.

Purpose: To evaluate the association between reconstruction techniques and subsequent graft rupture and return-to-sport rates in patients aged 16 to 30 years participating in pivoting sports.

Study Design: Cohort study; Level of evidence, 2.

Methods: A prospective study of patients undergoing primary ACL reconstruction with a bone–patellar tendon–bone (B-PT-B) graft, quadrupled hamstring tendon (4HT) graft, or hamstring tendon graft combined with anterolateral ligament reconstruction (HT+ALL) was conducted by the Scientific ACL NeTwork International (SANTI) Study Group. Survivorship data from Kaplan-Meier analysis were analyzed in multivariate Cox regression models to identify the prognosticators of graft ruptures and return to sport.

Results: Five hundred two patients (mean age, 22.4 ± 4.0 years) with a mean follow-up of 38.4 ± 8.5 months (range, 24-54 months) were included. There were 105 B-PT-B, 176 4HT, and 221 HT+ALL grafts. The mean postoperative scores at latest follow-up were the following: Lysholm: 92.4 ± 8.6, Tegner: 7.4 ± 2.1, and subjective International Knee Documentation Committee (IKDC): 86.8 ± 10.5 for B-PT-B grafts; Lysholm: 91.3 ± 9.9, Tegner: 6.6 ± 1.8, and subjective IKDC: 85.4 ± 10.4 for 4HT grafts; and Lysholm: 91.9 ± 10.2, Tegner: 7.0 ± 2.0, and subjective IKDC: 81.8 ± 13.1 for HT+ALL grafts. The mean side-to-side laxity was 0.6 ± 0.9 mm for B-PT-B grafts, 0.6 ± 1.0 mm for 4HT grafts, and 0.5 ± 0.8 mm for HT+ALL grafts. At a mean follow-up of 38.4 months, the graft rupture rates were 10.77% (range, 6.60%-17.32%) for 4HT grafts, 16.77% (range, 9.99%-27.40%) for B-PT-B grafts, and 4.13% (range, 2.17%-7.80%) for HT+ALL grafts. The rate of graft failure with HT+ALL grafts was 2.5 times less than with B-PT-B grafts (hazard ratio [HR], 0.393; 95% CI, 0.153-0.953) and 3.1 times less than with 4HT grafts (HR, 0.327; 95% CI, 0.130-0.758). There was no significant difference in the graft failure rate between 4HT and B-PT-B grafts (HR, 1.204; 95% CI, 0.555-2.663). Other prognosticators of graft failure included age ≤25 years ($P = .012$) and a preoperative side-to-side laxity >7 mm ($P = .018$). The HT+ALL graft was associated with higher odds of returning to preinjury levels of sport than the 4HT graft (odds ratio [OR], 1.938; 95% CI, 1.174-3.224) but not compared with the B-PT-B graft (OR, 1.460; 95% CI, 0.813-2.613).

Conclusion: In a high-risk population of young patients participating in pivoting sports, the rate of graft failure with HT+ALL grafts was 2.5 times less than with B-PT-B grafts and 3.1 times less than with 4HT grafts. The HT+ALL graft is also associated with greater odds of returning to preinjury levels of sport when compared with the 4HT graft.

Keywords: knee; anterior cruciate ligament; anterolateral ligament; graft rupture; return to sport

Graft ruptures are a major concern after anterior cruciate ligament (ACL) reconstruction. Reported rates vary from 1.4% to 18%,[16,20,21,31,48,50] reflecting that the cause of reruptures is multifactorial. Graft choice has been extensively studied as a potential prognosticator of reruptures

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after primary reconstruction, but despite several randomized controlled trials and meta-analyses, no major difference has been demonstrated between the most common autograft types utilized.[3,12,14,29,51] The influence of graft choice on rates of return to sport has also been evaluated, and similarly, no important differences have been identified. A recent systematic review has demonstrated that, on average, only 65% of patients return to their preinjury level of sport and only 55% to competitive sport.[2] These important clinical problems have led to a trend away from surgical techniques utilizing transtibial drilling to favor a more anatomic position of the femoral tunnel using either anteromedial or outside-in (including all-inside) techniques.[40] However, this has not been associated with the expected reduction in the rate of revision surgery.[37] ACL reconstruction utilizing a double-bundle technique instead of a single-bundle technique has also been investigated. While a recent systematic review demonstrated some improvements in postoperative stability, no differences in clinical results or the risk of graft failure were seen between the 2 techniques.[26] It is therefore apparent that despite advances in surgical techniques, both graft ruptures and low rates of return to sport remain important clinical problems.[2,14,16,20,21,31,48,50]

It is for this reason that there is currently great interest in the role of the anterolateral structures of the knee in controlling rotatory laxity and their ability to share loads with the ACL graft.[5,18,39,44] However, there are concerns, based on past studies and current expert opinion, that lateral extra-articular reconstruction is nonanatomic and may potentially overconstrain the joint because of altered biomechanics.[9] Recent advances in the scientific understanding of the anatomy, histology, and biomechanics of the anterolateral aspect of the knee have allowed the development of anatomic anterolateral ligament (ALL) reconstruction.[6,15,34,36,38,39,45] To date, only limited clinical results have been published, and these support a potential role for reducing the rate of ACL graft ruptures.[30,41,45]

It is recognized that young patients participating in pivoting sports are at the highest risk of graft ruptures.[16,20,31] Thus, the aim of this study was to report the clinical outcomes of ACL reconstruction in this particularly high-risk population using 3 different types of autograft: bone–patellar tendon–bone (B-PT-B), quadrupled hamstring tendon (4HT), and hamstring tendon combined with ALL reconstruction (HT+ALL). The hypothesis of the study was that the HT+ALL graft would be associated with decreased rates of ACL graft ruptures and increased rates of return to sport compared with the other graft types.

METHODS

This study received institutional review board approval, and all patients gave valid consent to participate. No financial incentives were provided. Between January 1, 2012 and May 31, 2014, 1346 consecutive patients underwent ACL reconstruction performed by the senior surgeon (B.S.-C.), and their outcome data were collected prospectively. For the purposes of this study, a subgroup of this overall population was selected. This included all young patients (aged 16-30 years) who were participating in pivoting sports before injury. This population was chosen as they were deemed at a high risk of graft ruptures, which was the main end point of this study.[16,20,31] Patients with collateral ligament injuries, with multiligament injuries, or undergoing other major concomitant procedures (eg, high tibial osteotomy) were excluded.

Included patients had undergone surgery with 1 of 3 different surgical techniques described below: B-PT-B, 4HT, or HT+ALL. The decision to use a particular type of graft was based on patient factors/choice and the senior surgeon evolving indications for concomitant ALL reconstruction. During the study period, there was a trend toward more frequently using HT+ALL grafts with the progression of time. This is because of the confidence built on an increasing duration of follow-up with excellent clinical outcomes[45] for patients with recognized risk factors for a graft rupture. During surgery, concomitant injuries (eg, meniscal and chondral lesions) were also addressed if indicated.

ACL Reconstruction With a B-PT-B Graft[13]

A 10 mm–diameter B-PT-B graft was harvested with a 9 to 11 × 25–mm bone wedge at the level of the tibial tuberosity and a 10 × 15–mm bone plug at the level of the patella. After the tunnels were drilled, the B-PT-B autograft was passed anterograde from the femur to the tibia with a pull-through technique under direct arthroscopic vision. Once the graft was seated in the femoral tunnel with press-fit fixation, the knee was placed at 20° of flexion, and tibial fixation was achieved with a 9-mm bioabsorbable interference screw (Bio-Interference screw; Arthrex) placed anteriorly to the graft (Figure 1A).

ACL Reconstruction With a 4HT Graft[43]

Grafts were harvested with an open-ended tendon stripper, preserving the tibial insertion, thereby improving fixation and vascularity of the graft.[33] An outside-in femoral

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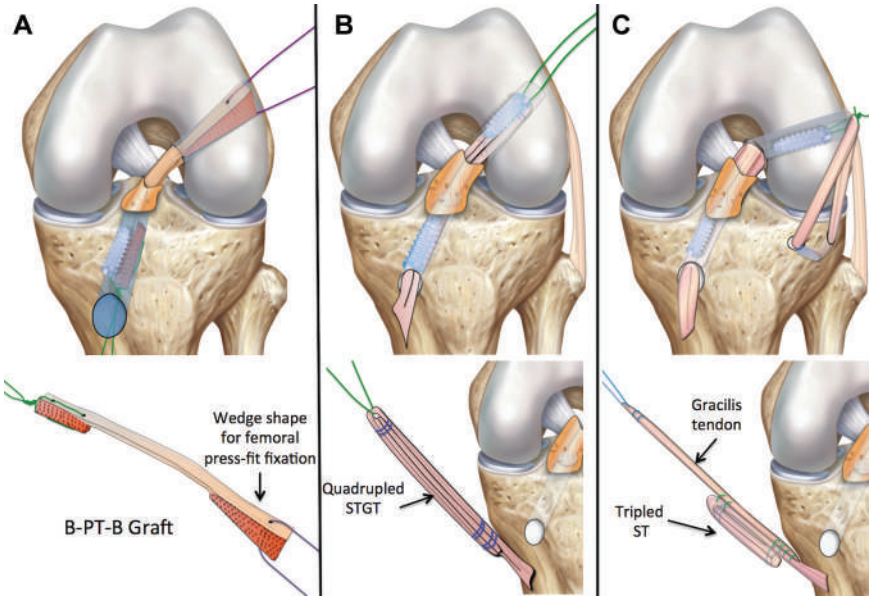

Figure 1. Illustration of anterior cruciate ligament reconstruction with a (A) bone–patellar tendon–bone (B-PT-B) graft, (B) quadrupled hamstring tendon (4HT) graft, and (C) hamstring tendon graft combined with anterolateral ligament reconstruction (HT+ALL).

tunnel was created, and then a tibial tunnel was drilled. The graft was routed from the tibia to the femur. Tibial fixation was achieved with a resorbable interference screw (Bio-Interference screw). The graft was then tensioned and fixed at 20° of flexion with a femoral resorbable interference screw (Bio-Interference screw) in an "outside-in" manner through a lateral incision (Figure 1B).

ACL Reconstruction With an HT+ALL Graft[42,45]

The gracilis tendon graft was detached and sutured to the tripled semitendinosus tendon graft with its tibial attachment preserved. The ACL graft was then composed of a tripled semitendinosus tendon with an additional strand of the gracilis tendon, the additional length of which was the ALL graft (Figure 1C). The sleeve of the outside-in femoral guide (Arthrex) was placed proximal and posterior to the lateral epicondyle at the femoral origin of the ALL and the intra-articular target at the ACL femoral origin.

For ALL reconstruction, 2 stab incisions were made approximately 1 cm distal to the joint line: one just posterior to the Gerdy tubercle and the second one just anterior to the fibula head. A 4.5-mm drill was used to create a bony tunnel on the tibia. A suture was then passed in a retrograde fashion to create a loop for graft passage. The knee was then taken through range of motion to ensure nonisometry of the ALL graft. An appropriately positioned graft was tight in extension and slack in flexion.[6,7,44]

The HT+ALL grafts were routed proximally through the knee and fixated with 2 interference screws (Bio-Interference screw) at 20° of flexion. The ALL graft was then routed deep to the iliotibial band from the femur to the tibia and subsequently shuttled through the tibial bony tunnel and back proximally to the femur. A 5.5-mm interference screw (Bio-Tenodesis screw; Arthrex) was then placed into the tibial anterior bone tunnel with the knee in full extension, leading to automatic neutral rotation. Proximally, the sutures holding the ACL graft were then tied around the ALL graft in full extension and neutral rotation.

Postoperative Course

Postoperatively, patients participated in a standardized rehabilitation program, which was the same for all 3 reconstruction techniques, entailing brace-free, immediate full weightbearing after the procedure and progressive range of motion exercises. Early rehabilitation was focused on obtaining full extension and quadriceps activation. A gradual return to sport activities was allowed starting at 4 months for nonpivoting sports, at 6 months for pivoting noncontact sports, and at 8 to 9 months for pivoting contact sports.

Patients were assessed preoperatively and postoperatively with the subjective International Knee Documentation Committee (IKDC) evaluation form and postoperatively also with the Lysholm and Tegner scores. Physical examinations were performed preoperatively and at the following postoperative intervals by an author who was not the senior surgeon (M.C.): weeks 3 and 6 and months 3, 6, and 12. This examination included range of motion, the Lachman test, and side-to-side laxity testing with a Rolimeter arthrometer (Aircast). At 6 months, all patients underwent isokinetic testing before returning to sport. When the isokinetic test showed a deficit above 20% in eccentric or concentric hamstring strength or any quadriceps deficit, return to sport was deferred, and repeat testing was performed 2 months later.

Patients were typically discharged from the clinic at 12 months, but long-term follow-up was conducted by a telephone interview or review in the clinic if a new injury had occurred. A graft rupture was determined by the clinical examination, side-to-side laxity greater than 4 mm

with the Rolimeter, and a magnetic resonance imaging (MRI) evaluation.

At the end of the study period, all patients underwent a telephone interview that comprised the following standardized questions:

- Did you sustain a new injury to your operated knee?
  - If yes, was the graft rupture demonstrated on MRI?
  - If yes, did you already undergo revision surgery in another orthopaedic department?

Patients who did not sustain a graft rupture were also asked the following question:

- Did you return to your preinjury sport level?

To assess the index procedure, patients undergoing contralateral ACL reconstruction within 12 months of the study end point or patients undergoing a reoperation for other causes within 3 months of the study end point were excluded from return-to-sport analyses.

Statistical Analysis

All calculations were made with SAS for Windows (Version 9.4; SAS Institute Inc) with the level of statistical significance set at $P < .05$. Descriptive data (mean, median, range, proportion) are reported for the entire series. The baseline characteristics of patients and postoperative outcomes were compared between the groups with the use of analysis of variance for heterogeneity (Gaussian variables), the Kruskal-Wallis test (ordinal variables or non-Gaussian variables), and the chi-square test for proportions, as appropriate. The Bonferroni-Holm correction for multiple testing was applied on baseline comparisons.

The Kaplan-Meier method was used to estimate the cumulative graft failure rate and the stratified log-rank statistic to select predictors in univariate analyses. A Cox proportional hazards regression model was used to perform an adjusted analysis of time to graft failure. The chi-square test was used to determine factors associated with the increased likelihood of returning to the preinjury sport level. A multivariate logistic model was used to perform an adjusted analysis on the prognostic factors identified in the univariate analyses, accounting for demographic differences between the groups.

RESULTS

Patients

Overall, 1346 patients underwent ACL reconstruction during the study period, of whom 541 met the inclusion criteria. The flow of patients is demonstrated in Figure 2. Thirty-nine (7.2%) patients were lost to follow-up despite attempts to contact them by telephone, mail, and their general practitioner, leaving a final population of 502 patients. The final study population comprised 105 B-PT-B, 176 4HT, and 221 HT+ALL grafts.

The patient characteristics are summarized in Table 1. The mean age for the study cohort was 22.4 ± 4.0 years (range, 16-30 years); 72.5% (n = 364) were male. The mean duration of follow-up was 38.4 ± 8.5 months (range, 24-54 months). There were no significant differences between each of the groups with respect to the mean time between injury and surgery ($P = .73$), the preoperative side-to-side laxity ($P = .73$), and the rate and type/location of meniscal tears ($P = .32$) (25.4% of the patients had a medial meniscal tear, 15.4% had a lateral meniscal tear, and 12.8% had tears of both menisci). There was also no difference between the groups with respect to the surgical treatment for meniscal tears (2.8% medial meniscectomy, 35.4% medial meniscal repair, 4.3% lateral meniscectomy, and 23.9% lateral meniscal repair).

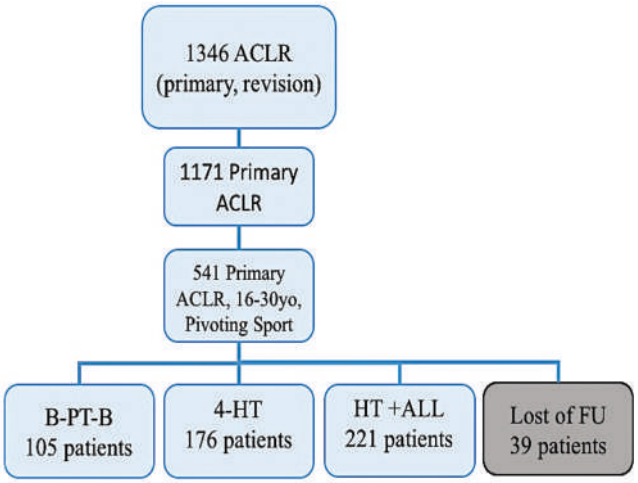

Figure 2. Patient flow through the study. 4HT, quadrupled hamstring tendon; ACLR, anterior cruciate ligament reconstruction; B-PT-B, bone–patellar tendon–bone; FU, follow-up; HT+ALL, hamstring tendon combined with anterolateral ligament reconstruction.

However, there were significant differences between the groups with respect to sex ($P < .0001$) (male patients: 4HT: 65.9%, B-PT-B: 91.4%, and HT+ALL: 68.8%), age ($P = .0004$), and sport participation ($P < .0001$) (contact sports: 4HT: 64.2%, B-PT-B: 82.9%, and HT+ALL: 83.7%), and these factors were therefore accounted for in subsequent multivariate analyses. Thirty-nine professional athletes participated in this series: 6 in the HT group, 13 in the B-PT-B group, and 20 in the HT+ALL group.

Postoperative Outcomes

Postoperative outcome data are shown in Table 2. No significant differences were found between the groups with respect to the mean preoperative and postoperative subjective IKDC scores, side-to-side laxity, and postoperative Lysholm and Tegner scores.

Graft Ruptures

At latest follow-up, the overall graft failure rate was 8% (40/502). This occurred at a mean of 18.5 ± 9.5 months (range, 5-42 months) after the index procedure. Multivariate analysis was performed to identify predictive factors of

TABLE 1
Patient Demographics[a]

	All Patients (N = 502)	4HT (n = 176)	B-PT-B (n = 105)	HT+ALL (n = 221)	*P* Value
Follow-up, mean ± SD (range), mo	38.4 ± 8.5 (24-54)	41.6 ± 7.0 (24-54)	39.2 ± 8.8 (24-54)	35.4 ± 8.4 (24-53)	**<.0001**
Male sex, n (%)	364 (72.5)	116 (65.9)	96 (91.4)	152 (68.8)	**<.0001**
Age, mean ± SD, y	22.4 ± 4.0	23.5 ± 4.0	22.1 ± 3.7	21.8 ± 4.0	**.0004**
Time from injury to surgery, mean ± SD, mo	5.2 ± 9.9	4.5 ± 6.2	6.0 ± 15.2	5.3 ± 9.0	.7346
Type of sport,[b] n (%)					**<.0001**
Contact	385 (76.7)	113 (64.2)	87 (82.9)	185 (83.7)	
Noncontact	117 (23.3)	63 (35.8)	18 (17.1)	36 (16.3)	
Meniscal tear, n (%)					.2157
None	232 (46.2)	95 (54.0)	41 (39.0)	96 (43.4)	
Medial	128 (25.5)	39 (22.2); meniscectomy (2.9%) and suture (27.3%)	34 (32.4); meniscectomy (4.8%) and suture (43.8%)	55 (24.9); meniscectomy (1.8%) and suture (38.0%)	
Lateral	77 (15.3)	28 (15.9); meniscectomy (4.0%) and suture (19.8%)	13 (12.4); meniscectomy (5.7%) and suture (22.9%)	36 (16.3); meniscectomy (4.0%) and suture (27.6%)	
Both	65 (13)	14 (8.0)	17 (16.2)	34 (15.4)	
Contralateral ACL reconstruction before index procedure, n (%)	58 (11.6)	12 (6.8)	21 (20.0)	25 (11.3)	**.0295**

[a]Chi-square test for nominal variables and analysis of variance for heterogeneity for continuous variables. *P* values are corrected by the Bonferroni-Holm method to avoid issues related to multiple testing. Bolded *P* values indicate statistical significance. 4HT, quadrupled hamstring tendon; ACL, anterior cruciate ligament; B-PT-B, bone–patellar tendon–bone; HT+ALL, hamstring tendon combined with anterolateral ligament reconstruction.

[b]Type of sport: pivoting sport with contact (soccer, handball, basketball, rugby, motocross) and pivoting sport without contact (alpine skiing, fitness, gymnastics, tennis).

a graft rupture (Table 3). The variables studied that did not show a significant association with graft ruptures included sex, time from injury to surgery, contact versus noncontact pivoting sports, and need for meniscal resection/repair. The variables that were demonstrated to be important predictive factors of graft failure were the technique of ACL reconstruction used ($P = .034$), age $\leq$25 years ($P = .012$), and preoperative side-to-side laxity measured by the Rolimeter ($P = .018$).

At a mean follow-up of 38.4 months, the graft rupture rates were 10.77% (range, 6.60%-17.32%) for the 4HT group, 16.77% (range, 9.99%-27.40%) for the B-PT-B group, and 4.13% (range, 2.17%-7.80%) for the HT+ALL group.

Figure 3 shows the survivorship data from Kaplan-Meier analysis, free from graft ruptures, stratified by the ACL reconstruction technique. When the differences in the demographics of the population relating to age and sex and preoperative side-to-side laxity were accounted for, the rate of graft failure in the HT+ALL group was 3.1 times less than in the 4HT group (hazard ratio [HR], 0.327; 95% CI, 0.130-0.758) and 2.5 times less than in the B-PT-B group (HR, 0.393; 95% CI, 0.153-0.953). There was no significant difference in the graft failure rate between the 4HT and B-PT-B groups (HR, 1.204; 95% CI, 0.555-2.663).

Other factors that demonstrated important associations with graft ruptures in multivariate analysis were age $\leq$25 years (3.4 times more risk of graft ruptures compared with older patients [HR, 3.433; 95% CI, 1.433-10.175]) and a preoperative side-to-side laxity $>$7 mm (3.2 times more risk of graft ruptures compared with those with a difference $\leq$7 mm [HR, 0.314; 95% CI, 0.131-0.677]). These data are also presented in Table 3.

Return to Sport

Overall, 93% of patients returned to sport at latest follow-up. The rate of return to self-described preinjury levels of sport was 64.6% (272/421). In the professional athlete population (n = 39), 5 patients incurred a graft rupture (3 B-PT-B, 1 4HT, 1 HT+ALL), and 6 incurred a contralateral ACL injury and were excluded from analyses of return to preinjury levels of sport. Of the remaining 28 professional athletes, all returned to their preinjury level of sport.

Several variables were demonstrated to lack a prognostic value in predicting the return to preinjury levels of sport in univariate analysis (Table 4). Age $\leq$25 years ($P = .238$), contact or noncontact sport ($P = .678$), contralateral ACL reconstruction before ($P = .083$) and after ($P = .176$) the index procedure, or reoperation ($P = .198$) all had no influence on returning to preinjury sport levels.

Multivariate logistic analysis was performed to identify factors predictive of returning to preinjury levels of sport (Table 5). Female sex (odds ratio [OR], 0.589; 95% CI, 0.368-0.941) was associated with a significantly lower likelihood of returning to preinjury levels of sport ($P = .027$). The HT+ALL graft was associated with higher odds of returning to preinjury levels of sport than the 4HT graft (OR, 1.938; 95% CI, 1.174-3.224) but not compared with the B-PT-B graft (OR, 1.460; 95% CI, 0.813-2.613). The absence of a meniscal tear was associated with a greater

TABLE 2
Postoperative Outcomes[a]

	All Patients		4HT		B-PT-B		HT+ALL		
	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	*P* Value
Subjective IKDC score	58.2 ± 17.4	84.4 ± 11.6	59.4 ± 16.3	85.4 ± 10.4	56.5 ± 15.8	86.8 ± 10.5	57.2 ± 20.2	81.8 ± 13.1	.1640
Change in subjective IKDC score (postoperative – preoperative)		27.0 ± 15.7		26.9 ± 15.1		26.1 ± 15.6		27.7 ± 17.6	.8428
Lysholm score		91.8 ± 9.6		91.3 ± 9.9		92.4 ± 8.6		91.9 ± 10.2	.7848
Tegner score		7.0 ± 2.0		6.6 ± 1.8		7.4 ± 2.1		7.0 ± 2.0	.1054
Side-to-side laxity, mm	7.5 ± 1.6	0.5 ± 0.9	7.4 ± 1.5	0.6 ± 1.0	7.6 ± 1.6	0.6 ± 0.9	7.5 ± 1.6	0.5 ± 0.8	.3879
Change in side-to-side laxity (postoperative – preoperative), mm		–7.0 ± 1.7		–6.8 ± 1.8		–7.2 ± 1.7		–7.0 ± 1.7	.2719
Secondary meniscal procedure, n	22 total: 18 meniscectomy; 4 suture		7 meniscectomy		4 meniscectomy		7 meniscectomy; 4 suture		
Cyclops syndrome, n (%)	22 arthrolysis		11 (6.3)		5 (4.8)		6 (2.7)		

[a]Values are reported as mean ± SD unless otherwise indicated. *P* values are presented for the Kruskal-Wallis test. 4HT, quadrupled hamstring tendon; ACL, anterior cruciate ligament; B-PT-B, bone–patellar tendon–bone; HT+ALL, hamstring tendon combined with anterolateral ligament reconstruction; IKDC, International Knee Documentation Committee.

TABLE 3
Multivariate Analysis of Predictive Factors of Graft Failure[a]

Variable	Adjusted Hazard Ratio (n = 457)	95% CI	*P* Value
Surgical technique			**.034**
HT+ALL vs 4HT	0.327	0.130-0.758	
HT+ALL vs B-PT-B	0.393	0.153-0.953	
4HT vs B-PT-B	1.204	0.555-2.663	
Age			**.012**
≤25 y vs >25 y	3.433	1.433-10.175	
Type of sport			.144
Contact vs noncontact	2.060	0.851-6.160	
Sex			.084
Female vs male	0.420	0.139-1.034	
Preoperative side-to-side laxity			**.018**
≤7 mm vs >7 mm	0.314	0.131-0.677	

[a]Bolded *P* values indicate statistical significance. 4HT, quadrupled hamstring tendon; B-PT-B, bone–patellar tendon–bone; HT+ALL, hamstring tendon combined with anterolateral ligament reconstruction.

likelihood of returning to preinjury levels of sport (compared with a medial meniscal tear) (OR, 2.165; 95% CI, 1.289-3.655), and a medial meniscal tear was shown to be a predictive factor of worse outcomes than a lateral meniscal tear (OR, 0.315; 95% CI, 0.096-0.986).

Reoperation

One hundred twenty-eight patients (25.5%) underwent a reoperation after the index procedure. Among the 40 graft failures, 37 underwent revision ACL reconstruction, and 3 await revision surgery. Eight percent of patients (40/502) had a contralateral ACL rupture at a mean of 21.9 ± 8.7 months after the index procedure. There was no difference between the groups.

Fifty-one patients (10.2%) underwent a reoperation for ipsilateral, non–graft rupture–related causes. There was no significant difference between the groups with respect to the following causes for reoperation: (1) Twenty-two patients underwent secondary meniscal procedures with 18 secondary meniscectomies and 4 meniscal sutures. (2) Arthrolysis for cyclops syndrome was performed in 22 patients. (3) Two patients underwent mobilization under anesthesia for stiffness at 1.7 and 2.5 months after ACL reconstruction: one in the HT+ALL group and the other in the 4HT group. There was no increased risk of stiffness in the HT+ALL group. (4) We had 5 other complications: 1 lavage for septic arthritis (1 month after ACL reconstruction with a B-PT-B graft), 1 lavage for hemarthrosis (2 days after ACL reconstruction with an HT+ALL graft), and 3 tibial screw removals for cysts (5, 19, and 26 months after ACL reconstruction [1 patient in each group]).

DISCUSSION

This study demonstrates that ACL reconstruction using any of the 3 graft types provides good functional outcomes

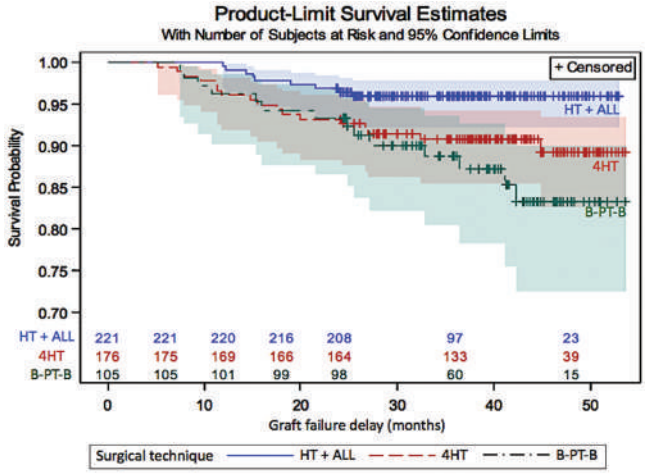

Figure 3. Survivorship data from Kaplan-Meier analysis stratified by anterior cruciate ligament reconstruction technique.

and reliably restores anteroposterior stability of the knee at a mean follow-up of 38.4 months. However, the key finding of this study was that patients with HT+ALL grafts had a 3.1 times less risk of graft ruptures than those with 4HT grafts and a 2.5 times less risk than those with B-PT-B grafts during the study period. The major advantage of the HT+ALL technique is the association with a significantly lower rerupture rate at midterm follow-up when compared with other techniques in this series. Other factors that were demonstrated to prognosticate an increased risk of graft ruptures were age ≤25 years and preoperative side-to-side laxity >7 mm. Although younger age has long been established as an important risk factor for graft ruptures,[20,31,35,48,49] preoperative side-to-side laxity is a more recently recognized important prognosticator.[22]

This study has focused on a young population participating in pivoting sports. The rupture rate in this high-risk population has been reported to be as high as 18% by other authors.[16,20,31,41,47] In this series, the failure rate of the B-PT-B group at 38.4 months of follow-up was 16.77%. This group was very similar to the HT+ALL group in terms of the percentage of patients who were participating in high-risk contact sports (~83%) and patients aged ≤25 years (~75%). However, the failure rate in the HT+ALL group was only 4.13% during the same follow-up period.

The importance of this study is that it is the first clinical series to demonstrate that anatomic ALL reconstruction is associated with a reduction in the rate of graft ruptures compared with other common graft choices. This finding can likely be attributed to load sharing with the ACL graft by extra-articular reconstruction. However, it is recognized that this in itself is not a new concept. Engebretsen et al[10] demonstrated a 43% reduction in the forces transmitted to the ACL graft because of load sharing by extra-articular tenodesis in a cadaveric study in 1990, and at a similar time, Noyes and Barber[32] reported clinical results at medium-term follow-up in a cohort of patients operated on between 1985 and 1987. They reported a graft failure rate of 16% versus only 3% when extra-articular tenodesis was performed and concluded that the extra-articular procedure appeared to provide support to the ACL graft by reducing deleterious forces and tibial displacements.

Contemporary literature has also reported similar findings. Marcacci et al[23,24] reported a 2% graft rupture rate at 5 years' follow-up using combined intra- and extra-articular reconstruction. Acquitter et al,[1] in a randomized prospective study, reported a 4% graft rupture rate in the group with extra-articular reconstruction compared with 12% with the isolated B-PT-B technique. Unfortunately, the study design was underpowered, and the difference between the 2 groups was not statistically significant

TABLE 4
Univariate Analysis of Factors Potentially Correlated to Returning to Preinjury Levels of Sport[a]

Variable	Return to Sport at Same Level	*P* Value
All (n = 421)	272 (64.6)	
Surgical technique		.231
4HT	88/147 (59.9)	
B-PT-B	54/85 (63.5)	
HT+ALL	130/189 (68.8)	
Sex		.074
Female	69/119 (58.0)	
Male	203/302 (67.2)	
Age		.238
≤25 y	187/281 (66.5)	
>25 y	85/140 (60.7)	
Type of sport[b]		.678
Contact	204/313 (65.2)	
Noncontact	68/108 (63.0)	
Location of meniscal tear		.065
None	139/195 (71.3)	
Medial	62/107 (57.9)	
Lateral	40/68 (58.8)	
Both	31/51 (60.8)	
Contralateral ACL reconstruction before index procedure		.083
Yes	244/369 (66.1)	
No	28/52 (53.8)	
Contralateral ACL reconstruction after index procedure		.176
Yes	0/1 (0)	
No	272/420 (64.8)	
Reoperation		.198
Yes	27/48 (56.3)	
No	245/373 (65.7)	

[a]Values are reported as n (%). Eighty-one of 502 patients were excluded from analysis of return to preinjury levels of sport because they underwent either contralateral ACL reconstruction within 12 months of the study endpoint or reoperation for other causes within 3 months of the study endpoint. *P* values are presented for the chi-square test to evaluate the likelihood of returning to sport at the same level. 4HT, quadrupled hamstring tendon; ACL, anterior cruciate ligament; B-PT-B, bone–patellar tendon–bone; HT+ALL, hamstring tendon combined with anterolateral ligament reconstruction.

[b]Type of sport: pivoting sport with contact (soccer, handball, basketball, rugby, motocross) and pivoting sport without contact (alpine skiing, fitness, gymnastics, tennis).

TABLE 5
Odds Ratios for Predictive Factors of Returning to Preinjury Levels of Sport[a]

Variable	Adjusted Odds Ratio (n = 419)	95% CI	*P* Value
Surgical technique			**.035**
HT+ALL vs 4HT	**1.938**	**1.174-3.224**	
HT+ALL vs B-PT-B	1.460	0.813-2.613	
4HT vs B-PT-B	0.753	0.409-1.371	
Sex			**.027**
Female vs male	**0.589**	**0.368-0.941**	
Location of meniscal tear			**.024**
None vs medial	**2.165**	**1.289-3.655**	
None vs lateral	0.682	0.224-1.997	
None vs both	0.717	0.228-2.174	
Medial vs lateral	**0.315**	**0.096-0.986**	
Medial vs both	0.331	0.098-1.063	
Lateral vs both	1.052	0.484-2.276	
Contralateral ACL reconstruction before index procedure			.064
No vs yes	1.811	0.963-3.400	

[a]Bolded values indicate statistical significance. 4HT, quadrupled hamstring tendon; ACL, anterior cruciate ligament; B-PT-B, bone–patellar tendon–bone; HT+ALL, hamstring tendon combined with anterolateral ligament reconstruction.

perhaps because of small sample sizes (n = 50). Ferretti et al,[11] in a very recent publication comparing isolated ACL reconstruction to ACL reconstruction combined with a modified MacIntosh procedure, also found a significantly reduced graft failure rate with the combined procedure. In a study focused on revision ACL reconstruction, Trojani et al[47] found that adding lateral tenodesis decreased failure rates and increased knee stability, showing a failure rate of 15% for isolated ACL reconstruction and only 7% for ACL reconstruction associated with lateral tenodesis.

Despite these promising results, other authors have reported concerns with adding lateral extra-articular procedures. These concerns have included additional donor site cosmesis problems, stiffness, loss of motion, patellofemoral crepitation, poor subjective results, and increased degenerative changes in the lateral compartment.[8,19,46] For those reasons, a combined HT+ALL technique was chosen compared with using the B-PT-B+ALL technique as it allows for just 1 femoral tunnel and the use of 1 graft, thus minimizing the risk of some of the potential complications. It is therefore reassuring that in this large series, there was no increased risk of these complications with the HT+ALL technique compared with other common techniques for ACL reconstruction. The reoperation rate of 10.4% is similar to other published data (13.5%-27.6%).[17,25] Several risk factors for reoperation after ACL reconstruction have been identified; among them, younger age and return to sport have been highlighted.[16,49] Most reoperations (69%) were performed within 1 year after ACL reconstruction. After the exclusion of graft ruptures and contralateral ACL reconstruction following the index procedure, the reoperation rates were 8.6% with B-PT-B grafts, 10.8% with 4HT grafts, and 10.4% with HT+ALL grafts. Moreover, in our series of 221 HT+ALL grafts, we did not observe any specific complications related to ALL reconstruction, and in no patients was there a necessity to cut the ALL because of concerns of limited range of motion.

It is recognized that concerns have existed regarding the risk of late osteoarthritis and varus deformity due to potential overtightening of the lateral compartment with extra-articular reconstruction since the 1980s.[8,34] However, Ferretti et al[11] recently demonstrated at a minimum 10-year follow-up that patients undergoing extra-articular reconstruction did not have an increased risk of osteoarthritis. The number of patients with grades II, III, and IV according to the Kellgren classification in the control group (25/49; 51%) was statistically higher than in the extra-articular reconstruction group (6/42; 14%) (P = .003). These findings are in agreement with other contemporary studies[52] that also did not find an increased risk of osteoarthritis with extra-articular tenodesis. Marcacci et al[23] did not find any increase in degenerative changes in the lateral compartment with more than 10 years' follow-up in patients without lateral meniscal tears that were subjected to combined intra- and extra-articular ACL reconstruction. Ferretti et al[11] suggested that the previous concept of lateral overtightening causing degenerative changes in the lateral compartment is unlikely to be correct. They postulated that the previously reported osteoarthritis might have been a result of the cautious postoperative protocol, which included immobilization in a plaster cast for up to 2 months postoperatively. Additional potential causative factors include a combination of imperfectly anatomic ACL reconstruction and nonanatomic extra-articular lateral tenodesis, using mostly an iliotibial band strand under the lateral collateral ligament, fixed in flexion, and often with the tibia in external rotation and delayed rehabilitation.[11]

Our series showed an excellent rate of return to sport, with 93% of the patients being able to return, which can probably be explained by our young population. However, similar to other series,[4,27-29] our rate of return to the preinjury level was only 64.6%. All professional athletes returned to the same preinjury level of sport regardless

of the graft used. The rate of return to the preinjury level of sport was 61.4% for the rest of the study population. It was demonstrated that the rate of return to the preinjury level of sport was higher with HT+ALL grafts (68.8%) compared with B-PT-B (63.5%) and 4HT grafts (59.9%). In our multivariate analysis, male sex, absence of a meniscal tear, and HT+ALL grafts were associated with significantly greater odds of returning to preinjury levels of sport.

The clinical results of this study are particularly important because they demonstrate the value of ALL reconstruction in reducing the rate of ACL graft ruptures. The prior controversy on the ALL has arisen predominantly because of a lack of clinical results. Most previous studies have investigated the role of the ALL in cadaveric specimens in the laboratory, which cannot be extrapolated to the clinical scenario in every situation. These have failed to account for the dynamic stabilizing forces and functional loads that occur in real life and also failed to reproduce the typical injury patterns associated with ACL ruptures. This reliance on laboratory rather than clinical studies has been further flummoxed by differing reports of the precise anatomy of the ALL and therefore a failure to understand its biomechanics and function.

The indications for combined ACL and ALL reconstruction are not yet clearly defined. However, the results of this study demonstrate that it is a safe procedure that reduces the rate of graft failure and increases the rate of return to preinjury levels of sport. We therefore propose that the indications for combined ACL and ALL reconstruction should be expanded. Our current indications include a grade III pivot shift, associated Segond fracture, chronic ACL rupture, high levels of sporting activity, participation in pivoting sports (eg, soccer, rugby, handball, basketball), patients $\leq$25 years old, preoperative side-to-side laxity $>$7 mm, lateral femoral notch sign on plain radiographs, and patients undergoing revision ACL reconstruction. In the authors' experience, ACL reconstruction with other techniques does not reliably confer anteroposterior and rotational control in these patients who are at a higher risk of reruptures. Longer term randomized comparative studies are necessary to determine more objectively the surgical indications for combined ACL and ALL reconstruction.

Limitations

The main limitation of this study is its retrospective and nonrandomized design, and our indications for each technique were not delineated before surgery. This resulted in differing numbers of patients in each group. The fact that the HT+ALL group was the largest reflects the trend in the senior author's practice (the HT+ALL technique has been used in $>$60% of patients since 2015). Therefore, in the absence of blinded randomization to the different groups, we cannot exclude the possibility of selection bias. However, as far as is possible, performing multivariate analyses that take into account demographic differences between the groups has mitigated this. The retrospective nature of the study also relied on patients recalling whether they underwent MRI that demonstrated graft ruptures after the index procedure, and this is potentially subject to recall bias.

A further limitation is that patients younger than 16 years and older than 30 years were excluded from the study, reducing the external validity of these results to that population. The lower age limit was selected to reflect the experience that ACL reconstruction in potentially skeletally immature patients is different than in adults. The upper age limit was determined on the empirical basis that patients over the age of 30 years are less likely to be participating regularly in pivoting sports. Although age did not significantly influence the graft rupture rate, it is possible that the inclusion of patients with a wider range of ages would have altered our findings. On the other hand, the selection of these age ranges is supported by the findings of Lind et al,[21] which demonstrated that the vast majority of revision cases were performed in patients older than 15 years.

CONCLUSION

In a high-risk population of young patients participating in pivoting sports, the rate of ACL graft failure with HT+ALL grafts is at least 2.5 times less than with other common ACL graft choices and is also associated with greater odds of returning to preinjury levels of sport when compared with 4HT grafts. Longer term randomized comparative studies are necessary to determine more objectively the surgical indications for combined ACL and ALL reconstruction.

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