Original Article

Anterior Cruciate Ligament Hybrid Remnant Preservation Reconstruction Demonstrates Equivalent Patient-Reported Outcomes and Complications as Traditional Anterior Cruciate Ligament Reconstruction After 1 Year

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Purpose: To compare the outcomes of anterior cruciate ligament (ACL) Hybrid Remnant Preservation Reconstruction (HRPR) with traditional anterior cruciate ligament reconstruction (ACLR) and determine differences in patient-reported outcomes, range of motion (ROM), and complications after 12 months. **Methods:** A retrospective cohort study of patients undergoing ACLR by a single surgeon from December 2020 to January 2022 was conducted. Patients undergoing ACL-HRPR were compared with control patients undergoing traditional ACLR with bone−patellar tendon−bone autograft. Preoperative and postoperative Patient-Reported Outcome Measurement Information System scores, International Knee Documentation Committee, and patient acceptable symptom state were recorded over 12 months. Any complications occurring 12 months postoperatively were collected. **Results:** The final analysis included 104 patients, with 39 undergoing ACL-HRPR compared with 65 ACLR controls. Patients who received HRPR were on average 19.46 ± 5.01 years old, with 51.28% being female, whereas control patients were, on average, 21.92 ± 7.71 years old with 50.77% being female. Total ROM was equivalent between groups, with complete terminal extension at 12 months. No significant differences were found for patient acceptable symptom state; Patient-Reported Outcome Measurement Information System-Physical Function, -Pain Interference, or -Depression; or International Knee Documentation Committee at 6 months and 12 months postoperatively. Total ROM was similar between the HRPR and control groups. No differences were found for timed 6-meter hop test, hop for distance, or KT-1000 side-to-side differences. Over the 12-month period, complication rates were similar between groups (10% vs 12% $P = .75$) were similar. **Conclusions:** ACL HRPR is associated with equivalent patient-reported outcomes, full ROM, and no differences in complications rates after 1 year compared with control patients in the present retrospective study. **Level of Evidence:** Level III, retrospective cohort study.

Anterior cruciate ligament (ACL) tears occur commonly, with a reported incidence of 68.6 per 100,000 person-years.[1] Reconstruction of the ACL has served as the mainstay of treatment to restore knee stability, biomechanics, and prevent long-term chondral or meniscal damage.[2] Considerable advances in arthroscopic anterior cruciate ligament reconstructions (ACLRs) have occurred through better characterization of the origin and insertion of the native ACL to achieve more anatomic tunnel position, improved fixation, and graft selection. Anatomic landmarks frequently are used to accurately place tunnels, often requiring debridement of the native ACL. However, there has been interest in preserving the tibial ACL remnant in the setting of reconstruction,[3,4] with multiple described techniques of ACL preservation.[5-12] Preservation of the native ACL remnant has been theorized to provide additional benefit from added proprioceptive nerve fibers and vascular blood supply to enhance healing. Various studies have touted its potential benefits with improved knee proprioception, graft incorporation,[13-15] and ultimately graft stability.[8,15]

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Previously, Sherman et al. characterized the morphology of ACL tears and identified that proximal avulsions or tears, types 1 and 2, were amenable to repair.[16,17] These tibial remnant repairs were performed open but were ultimately abandoned due to poor longer-term outcomes.[16,18,19] However, advances in arthroscopy have led to a re-emergence of ACL repair due to its minimal invasiveness while preserving the joint.[20] Studies have highlighted the ability of the ACL tibial remnant to heal with favorable outcomes. van der List et al.[21] summarized the outcomes of 13 studies, including 1,101 patients undergoing ACL repair, and found that patients achieved >85% of maximum patient-reported outcomes (PROs) and favorable KT-1000 side-to-side differences. However, these studies reported a 7% to 11% failure rate and were limited to a mean follow-up of 2.1 years. Presently, the short- and midterm outcomes of arthroscopic ACL repair techniques demonstrate some promise in the properly selected patient, but varied rates of rerupture and lack of long-term outcomes limit conclusions on the efficacy of these techniques.

With these emerging studies underscoring the potential benefits of preserving the remnant and the healing potential of this tissue in ACL repair, a technique of ACL Hybrid Remnant Preservation Reconstruction (HRPR) was developed.[22] For Sherman type 1 or 2 tears, our technique preserves the tibial remnant and tensions this tissue for repair in conjunction with an ACLR. Theoretically, augmenting an ACLR with preserved remnant should provide additional biologic healing potential from the remnant ACL while offering the stability of a reconstruction. Therefore, the present study was performed to compare the outcomes of ACL HRPR to traditional ACLR and determine differences in PROs, range of motion (ROM), and complications after 12 months. We hypothesized that patients undergoing HRPR would experience noninferior PROs, similar ROM, and similar safety profile with equivalent complication rates.

Methods

This study was approved by the institutional review board (#14880-01). A retrospective cohort study of patients undergoing ACLR from December 2020 to January 2022 by a single surgeon (V.M.) was conducted. Patients were included if they underwent primary ACL reconstruction with bone−patellar tendon−bone (BTB) with and without the ACL HRPR technique. During this study period, all patients were considered for ACL HRPR. Patients were indicated for HRPR intraoperatively if there was a Sherman type I or II ACL tear with a viable tibial remnant tissue quality that the senior surgeon thought was amenable to a repair. Those with proximal tears with relatively preserved tibial remnants were ideal candidates. Exclusion criteria consisted of patients aged 13 years and younger, presence of multiligamentous injury requiring surgical intervention, chronic tears >6 months, those undergoing hamstring autograft, revision ACLR, and follow-up <6 months. A retrospective chart review was performed to collect patient demographics, concomitant procedures, ROM, and PROs at the preoperative, 6-week, 3-month, 6-month, and 12-month postsurgical time intervals. PROs are routinely collected via a tablet computer (iPad; Apple, Cupertino, CA) for all clinical visits at our institution and are integrated into the electronic medical record. These include Patient-Reported Outcome Measurement Information System (PROMIS) - Physical Function (PF), - Pain Interference, - Depression, and International Knee Discussion Committee questionnaire responses. For the PROMIS-PF outcomes, a sample size of 50 per group (total of 100) is required to detect a mean difference of 4.6 in the change from preoperatively between the 2 treatment groups (HRPR vs standard ACLR) with 80% power, assuming the standard deviation is 8.1, alpha = 0.05, and 2-sided testing. The mean difference (or stated minimum clinically important difference) and the standard deviation estimate come from the article by Chen et al.[23]

Technique

The details of the surgical technique are described by Moutzouros and Jildeh.[22] As mentioned previously, patients with type I or II tears with preserved ACL tibial remnants with minimal adjacent scar were ideal candidates for ACL-HRPR. The BTB autograft was harvested first using a midline incision over the patellar tendon. Standard diagnostic knee arthroscopy was then performed. The intercondylar notch was then prepared with care to preserve the tibial remanent. Electrocautery was then used to undermine the tibial remnant from lateral to medial to create space for the tibial tunnel (Fig 1A). An open circular aiming guide was then used to insert a guide pin and then drill for the appropriately sized tunnel. Using a suture passing device, a cored suture was then passed through the tibial remnant for later repair (Fig 1B and Fig 2A). These sutures were protected for later use. A cannula was then inserted into the anteromedial portal of the knee with the suture remaining outside the cannula to allow for protection of the suture and full ability to drill and prepare our femoral tunnel for reconstruction. The knee was then hyperflexed, and a Beath pin was drilled through the femur using an over-the-top guide with appropriate offset to preserve the backwall of the tunnel. The femoral tunnel was then drilled using the appropriately sized cannulated reamer and depth of tunnel based on the size of the bone block. The cored sutures attached to the ACL remnant were passed through the Beath pin, which

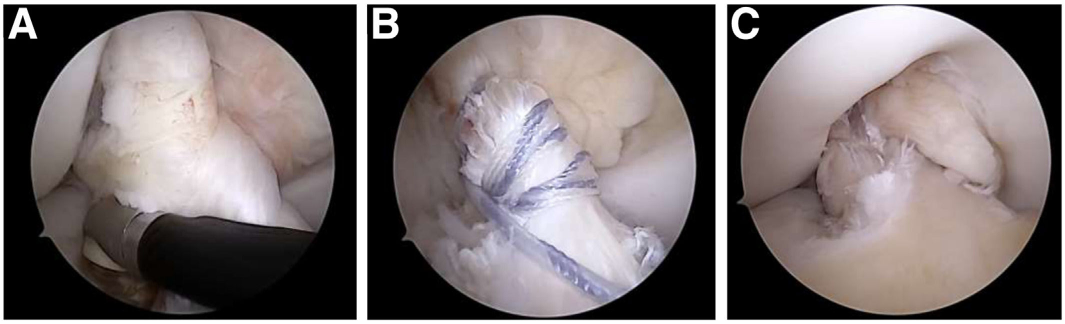

Fig 1. Arthroscopic images of the ACL Hybrid Remnant Preservation Reconstruction. (A) Arthroscopic view of the native ACL tibial remnant torn off the femoral origin. (B) The tibial remnant with nonabsorbable sutures passed through the tissue for later repair. (C) Final view of the bone patellar tendon bone reconstruction and repair of the ACL tibial remnant. (ACL, anterior cruciate ligament.)

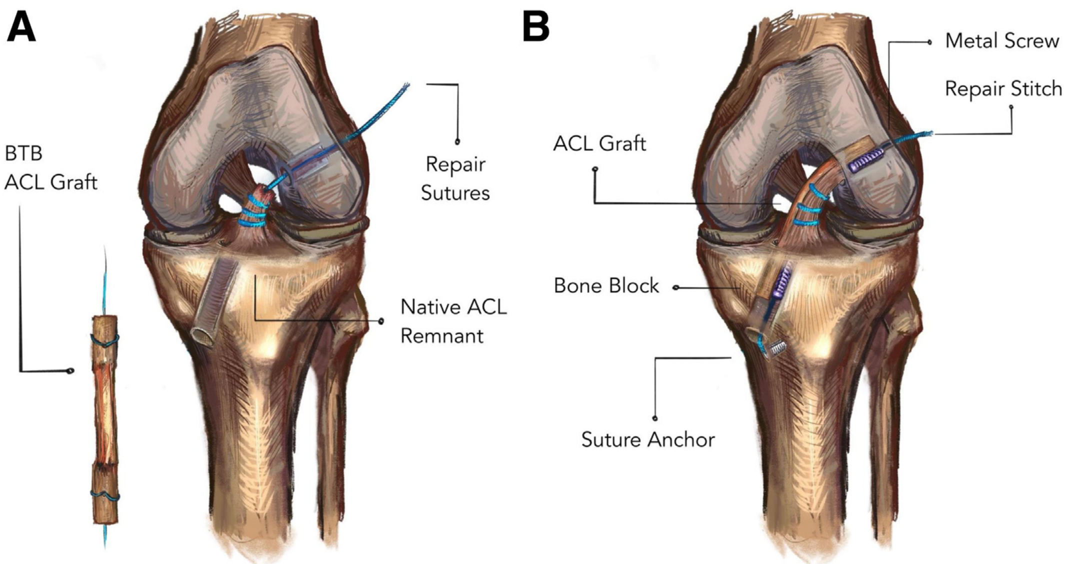

Fig 2. Illustration of the ACL Hybrid Remnant Preservation Reconstruction Procedure. (A) Nonabsorbable sutures passed through the native ACL remnant with tunnels drilled. (B) Final ACL reconstruction and remnant preservation construct. (ACL, anterior cruciate ligament; BTB, bone−patellar tendon−bone)

was pulled through the femoral tunnel for later tensioning on the ACL remnant. The BTB graft was then passed through the intercondylar notch and pulled through the femoral and tibia tunnels. With the ACL remnant suture passed through the femoral tunnel in conjunction with the BTB bone block, aperture fixation with a metal screw was then used to secure interference fit of both the graft bone block and remnant core suture with appropriate tension. Appropriate tensioning of the remnant was achieved by holding tension of the cored suture while the interference screw was applied in the femoral tunnel. The tibial tunnel was then fixed with a soft silk metal screw with the knee in 20 to 30° of flexion. The suture from the graft was then incorporated into a BioComposite anchor for backup fixation. The final HRPR construct appears in Figure 1C and 2B.

One-Year Testing

For patients undergoing surgery beginning in January 2021, patients were consented to participate in 12-month postoperative functional testing. Outcomes collected included bilateral knee dynamometer measurements for quadriceps strength, side-to-side anterior to posterior knee laxity testing using a KT-1000,[24] 6-meter timed single hop and single-leg triple hop for distance tests,[25] the leg symmetry index,[26] as well as a survey of subjective knee function. This survey question asked patients, “compared to your knee before ACL injury, how would you rate your overall knee function on a scale of 0-100%?”

ROM was collected using a goniometer. KT-1000 measurements were performed 3 times on each leg with 134 N maximum. The average of the 3 values was used in final data analysis. Quadriceps circumference

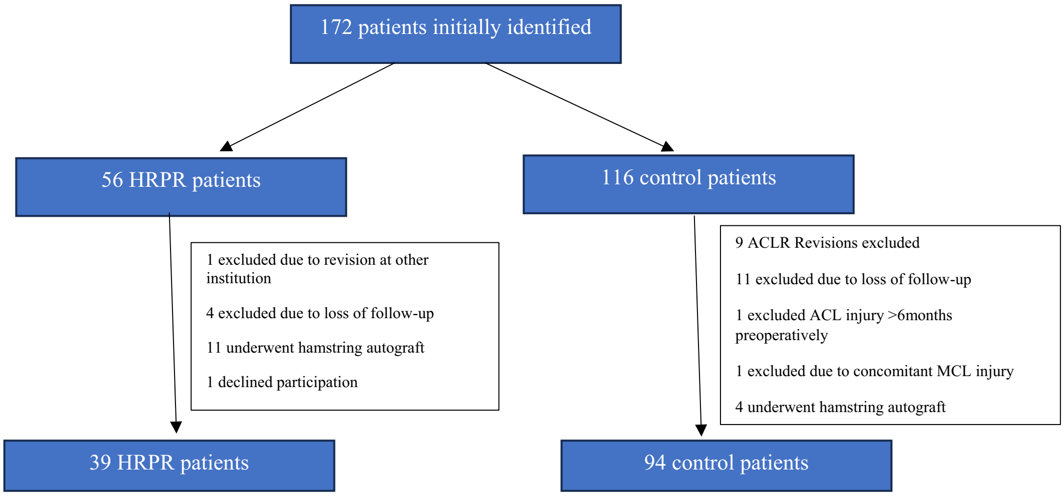

Fig 3. Flowchart of included patients in the final analysis. (ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; HRPR, hybrid remnant preservation reconstruction; MCL, medial collateral ligament.)

was measured 10 cm from the superior pole of the patella. A knee dynamometer was used to assess knee extension peak force, time to peak force, and average force over a 3-second period. Patients sat at the end of the examination table with legs bent at 90°. The patient's leg was then fixed to the leg of the examination table using a nonelastic belt. The patient was required to not hold on to the table during the entirety of the exam. Each leg was tested 3 times, and the mean values were used in final analysis. Patients then proceeded to complete a series of proprioceptive single-leg hop tests. A 6-meter timed single-leg hop test was performed in addition to a single-leg triple hop for distance. Patients were not able to rest their other foot on the ground at any time during the test, they could not touch the wall or floor, and they could not fall. If any of the previous criteria occurred, the trial would be reperformed.

Statistical Analysis

Descriptive statistics were performed, with continuous variable reported as means with standard deviations and categorical variables as counts and column percentages. Continuous variables were compared using the paired *t*-tests for normal distributions and the Mann−Whitney *U* test for non-normal distributions. Categorical variables were compared using χ^2 test or the Fisher exact test when appropriate. Statistical significance was set at *P* value < .05. All statistical analyses were performed with JMP (Version 16.2.0; SAS Institute Inc., Cary, NC).

Results

After we applied exclusion criteria, 39 patients undergoing ACL HRPR were included in the study and 65 controls undergoing traditional ACLR (Fig 3). The cohort experienced 29.8% loss to follow-up with regards to 1-year follow-up. The HRPR group had a mean age of 19.46 ± 5.01 years compared with 21.92 ± 7.71 years in the controls and 51.28% versus 50.77% female patients, respectively. There were no significant demographic differences (Table 1).

PROs at various time points up to 1 year are reported in Table 2. PROMIS-PF and -Pain Interference scores were not significantly different throughout the 1-year time period with the exception of PROMIS-Depression being greater in the control group preoperatively (44.35 ± 9.46 for HRPR vs 49.00 ± 9.25 for controls, *P* = .046). International Knee Discussion Committee scores were not statistically different throughout the 1-year time period. Patients achieved similar rates of patient acceptable symptom state at all time points, with 79.31% achieving patient acceptable symptom state in the HRPR group compared with 89.65% in the controls at 1 year. ROM between groups was not statistically different at any time point (Table 3). There was no reported loss of terminal extension in either group.

For 1-year functional testing, no differences were observed for 6-meter single leg timed hop test or single-leg triple hop for distance (Table 4). The limb symmetry index was equivalent between groups (89.33 ± 17.98 HRPR vs 92.62 ± 9.71 controls, *P* = .50). Patients subjectively rated their knee function as 84.07% in the HRPR compared with 89.65% in the controls, *P* = .13. Knee dynamometer average and peak force was greater in the HRPR compared with the control group in both the affected limbs (*P* = .01) (Table 4).

Complications up to 12 months after surgery revealed a 10% (n = 4) complication rate in the HRPR group compared with 12% (n = 8) in the control group (*P* = .75) (Table 5). For re-rupture/revision ACL procedures, there were 0 re-ruptures in the HRPR cohort compared with 4 in the controls (6.15%, *P* = .11). There were 2

Table 1. Demographics of Patients Undergoing ACLR

	HRPR (n = 39)	Control (n = 65)	*P* Value
Age, y, mean (SD)	19.46 (5.01)	21.92 (7.71)	.08
Sex			.96
Female	20 (51.28%)	33 (50.77%)	
Male	19 (48.72%)	32 (49.23%)	
BMI, mean (SD)	25.42 (5.02)	25.16 (5.63)	.81
Laterality			
Left	17 (43.59%)	33 (50.77%)	.48
Right	22 (56.41%)	32 (49.23%)	
Concomitant procedures	Chondroplasty = 1 Lateral meniscal repair = 5 Medial meniscal repair = 4 Lateral meniscectomy = 20 Medial meniscectomy = 5	Chondroplasty = 3 Lateral meniscal repair = 9 Medial meniscal repair = 11 Lateral meniscectomy = 31 Medial meniscectomy = 10 *P* = .45	

NOTE. Alpha < 0.05 denotes significance.

ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; HRPR, Hybrid Remnant Preservation Reconstruction; SD, standard deviation.

patients in the HRPR group who required a reoperation to address a new meniscal tear after the index ACL procedure. Cyclops lesions were not significantly different between groups, with n = 2 (3.07%) in the controls versus 0 in the HRPR group.

Discussion

The current study exhibits that ACL HRPR can be performed safely with comparable PROs, full ROM, and without increased complications over 12 months postoperatively compared with traditional ACLR. Patients receiving the HRPR technique with BTB autograft achieved full terminal extension without an increased incidence of cyclops lesions. Performance testing at 1 year yielded no differences in knee laxity, 6-meter timed hop test, or hop for distance. These retrospective findings suggest the noninferiority of the HRPR technique compared with traditional measures, but the long-term impact on proprioception, graft healing, and return to play remains to be elucidated.

Interest in preservation of the ACL remnant has vacillated over time. Histologic evidence from both sheep and human samples have highlighted the abundance of capillary networks and mechanoreceptors present in this remnant tissue. Preserving these elements of the native ACL has been theorized to provide additional biologic healing potential and improve knee proprioception.[13,15,27,28] These findings have led to various remnant-preservation (RP) techniques, ranging from simple preservation of the remnant stump tissue at the time of reconstruction to tensioning the tissue. Furthermore, emerging studies have purported the benefits of ACL repair in the setting of proximal tears, with restored biomechanics and quicker recovery compared with traditional ACLR.[29] However, the true long-term efficacy of these repair techniques remains to be seen, with failure rates ranging from 3.5% to 37.0% in select groups.[20,30-33] In response, we have developed a technique incorporating both the benefits of ACL repair/preservation and reconstruction. The rationale for developing our HRPR technique stems from similar principles and goals proposed previously: preservation of vascularity to improve graft synovilization and healing, tensioning native remnant mechanoreceptors to improve knee proprioception, and combining the stability of traditional reconstruction with the proposed biologic benefit of native ACL repair. Although significant advances have occurred, the existing literature has not elucidated factors leading to improved graft healing, proprioception, and improvements in the timeline of return-to-play, which we aim to improve with the development of the HRPR technique.

Overstuffing the notch with too large of an ACL graft is a risk for the development of cyclops lesions.[34,35] Haley et al.[35] reported a 7.2% incidence of arthrofibrosis in their quadriceps tendon autograft ACLR cohort, especially with femoral tunnels >9.25 mm in male patients. Similarly, RP in ACLR harbors the theoretical risk of overstuffing the intercondylar notch. Nakayama et al.[36] examined their outcomes of double-bundle ACLR with and without RP and found a 2-fold greater rate of patients requiring arthroscopic debridement due to terminal extension loss in 12% (6/50 patients) for the RP group compared with 4.0% (3/75 patients) in the nonpreservation group. However, despite these results suggesting larger remnant volume leading to extension loss, the incidence of symptomatic extension loss and cyclops lesions in ACL RP remains equivalent in multiple studies.[37-40] Our 1-year results after ACL HRPR demonstrate equivalent ROM, no statistically significant differences in reoperations, or cyclops lesions. However, although our study did not

Table 2. Patient-Reported Outcomes of Patients Undergoing HRPR

	Preoperative			6 Weeks			3 Months			6 Months			12 Months		
	HRPR	Control	*P* Value	HRPR	Control	*P* Value	HRPR	Control	*P* Value	HRPR	Control	*P* Value	HRPR	Control	*P* Value
PROMIS-PF	43.43	42.09	.37	41.74	41.21	.72	46.74	46.41	.76	51.88	51.54	.84	58.03	57.20	.77
(SD, n)	(8.27, n = 37)	(6.56, n = 65)		(6.02, n = 28)	(5.42, n = 35)		(3.82, n = 31)	(5.24, n = 44)		(5.79, n = 32)	(7.80, n = 50)		(12.42, n = 29)	(11.60, n = 44)	
PROMIS-PI	57.50	58.70	.37	56.34	55.96	.80	50.27	52.77	.79	50.27	49.79	.75	47.76	45.91	.29
(SD, n)	(6.75, n = 36)	(6.16, n = 64)		(6.46, n = 32)	(6.58, n = 49)		(6.14, n = 36)	(7.34, n = 52)		(6.14, n = 33)	(7.00, n = 53)		(7.20, n = 29)	(7.31, n = 45)	
PROMIS-D	44.35	49.00	.046	45.71	44.93	.85	43.17	45.67	.38	43.40	42.63	.75	41.35	41.60	.91
(SD, n)	(9.46, n = 26)	(9.25, n = 46)		(8.46, n = 7)	(8.97, n = 15)		(7.56, n = 18)	(9.91, n = 24)		(8.55, n = 20)	(8.29, n = 32)		(7.46, n = 23)	(9.22, n = 40)	
IKDC	56.00	48.92	.06	53.86	51.84	.73	58.62	64.75	.06	76.80	74.44	.54	84.55	85.03	.87
(SD, n)	(14.84, n = 29)	(15.80, n = 48)		(8.84, n = 7)	(13.98, n = 16)		(8.59, n = 18)	(10.68, n = 22)		(13.30, n = 24)	(15.25, n = 35)		(9.85, n = 24)	(12.36, n = 39)	
PASS	48.65%	36.51%	.234	64.52%	55.10%	.41	63.89%	58.49%	.61	72.72%	71.70%	.92	79.31%	89.65%	.15
(n)	(n = 37)	(n = 63)		(n = 31)	(n = 49)		(n = 36)	(n = 54)		(n = 33)	(n = 53)		(n = 29)	(n = 46)	

NOTE. Alpha <0.05 denotes significance.

-D, depression; IKDC, International Knee Documentation Committee; n, number; PASS, patient acceptable symptomatic state; -PF, physical function; -PI, pain interference; PROMIS, Patient-Reported Outcome Measurement Information System; SD, standard deviation.

Table 3. Measured ROMs at Preoperative, 6-Week, 3-Month, 6-Month, and 12-Month Follow-Up

	Preoperative		6 Weeks		3 Months		6 Months		12 Months	
	Average (SD, n)	*P* Value	Average (SD, n)	*P* Value	Average (SD, n)	*P* Value	Average (SD, n)	*P* Value	Average (SD, n)	*P* Value
HRPR affected limb	109.49 (16.98, 39)	.25	109.41 (16.40, 37)	.54	122.69 (7.87, 36)	.25	127.03 (7.68, 37)	.30	132.72 (10.52, 29)	.98
Control affected limb	113.31 (16.04, 65)		106.97 (20.19, 60)		120.30 (10.58, 57)		125.61 (5.43, 57)		132.80 (14.31, 46)	

NOTE. Alpha <0.05 denotes significance.

HRPR, Hybrid Remnant Preservation Reconstruction; n, number; ROM, range of motion; SD, standard deviation.

Table 4. 1-Year Function Testing for Patients Undergoing ACLR

	HRPR			Control			
	Affected Limb	Unaffected Limb	*P* Value Between Limbs	Affected Limb	Unaffected Limb	*P* Value Between Limbs	*P* Value Between Affected Limbs
Timed hop test (SD, n)	2.78 (0.74, 15)	2.69 (0.80, 15)	.75	3.38 (1.77, 24)	2.81 (0.89, 24)	.16	.23
Hop distance (SD, n)	369.35 (112.20, 14)	411.62 (87.77, 14)	.28	349.28 (123.99, 24)	387.01 (112.56, 24)	.28	.62
KT-1000 (SD, n)	3.35 (1.84, 15)	2.81 (1.37, 15)	.15	4.43 (2.36, 26)	4.17 (3.29, 26)	.75	.21
KT-1000 side-to-side difference (affected leg-unaffected leg) (SD, n)	−0.78 (1.35, 14)		—	−0.25 (3.11, 26)		—	.56
Knee dynamometer average force (SD, n)	64.43 (15.21, 14)	75.00 (24.41, 14)	.18	49.96 (17.50, 26)	58.62 (19.41, 26)	.10	**.01**
Knee dynamometer peak force (SD, n)	77.79 (17.34, 14)	92.84 (32.77, 14)	.14	59.32 (20.79, 26)	69.39 (22.14, 26)	.10	**.01**
Knee dynamometer force time peak (SD, n)	2.19 (.82, 14)	2.35 (.64, 14)	.57	2.34 (.76, 26)	2.43 (.66, 26)	.65	.55
Quadriceps circumference (SD, n)	47.7 (5.33, 14)	48.44 (4.83, 14)	.71	44.08 (5.66, 25)	44.46 (5.59, 25)	.81	.06
Range of motion (SD, n)	132.72 (10.53, 29)	130.21 (24.39, 14)	.64	132.80 (14.31, 46)	138.92 (12.32, 26)	.07	.98

NOTE. Alpha <0.05 denotes significance, which are bolded.
ACLR, anterior cruciate ligament reconstruction; HRPR, Hybrid Remnant Preservation Reconstruction; n, number; SD, standard deviation.

perform second-look arthroscopy or routinely collect magnetic resonance imaging (MRI) scans postoperatively, the control group yielded a 2-fold greater rate of complications with 3 symptomatic cyclops lesions compared with 0 in the HRPR group. We hypothesize that preservation of the tibial remnant may prevent anterior tibial tunnel placement by placing the graft at the anatomic insertion site of the native ACL.

Preservation of the tibial ACL remnant also may enhance biologic healing potential, with theoretical benefits of improved graft vascularization and lower rates of re-rupture. Kim et al.[12] performed a prospective randomized control trial comparing remnant-tensioning single-bundle with double-bundle ACLR without remnant preservation. At 2 years of follow-up, no differences were observed in terms of KT-2000 side-side-side differences, PROs, and second-look arthroscopic findings. However, at 1 year, dynamic contrast-enhanced MRI, which served as a proxy for graft vascularity, revealed an increased normalized area under the curve for the remnant-tensioning group compared with controls. These MRI findings of increased vascularity may be an indicator of increased synovilization and incorporation of the reconstructed graft.[41] Kondo et al.[42] investigated the effect of remnant preservation ACLR and found improved graft synovial coverage in the remnant group at second-look arthroscopy. However, these results have not been replicated in any other study thus far related to RP in ACLR. Overall, the evidence of improved graft integrity, quality, and synovial coverage has been similarly reported in other studies,[43,44] but the clinical significance of these findings has yet to be determined.

Although performance/functional testing was limited to a subset of patients in the present study, we found no differences in KT-1000 side-to-side differences or 6-meter/timed hop testing between groups, suggesting that the HRPR technique is associated with noninferior outcomes with respect to stability and function 12 months postoperatively. There has been suggestion of improved knee stability with remnant preservation in ACLR, as well as proprioception.[8,42,45] Adachi et al.[8] found that at 2 years, ACLR augmented with RP led to lower AP laxity via KT-2000 testing and improved joint position sense of the knee using a passive angle reproduction test, which asks patients to estimate their degree of knee flexion using a standardized instrument. The influence of remnant preservation on proprioception remains unclear, however. Cho et al.[46] performed a systematic review to assess knee proprioception in ACLR RP. Within 12 months after surgery, 3 of 4 studies preserving the remnant without tensioning the tissue exhibited statistically significant improvements in joint position sense,[47-49] whereas the remnant-tensioning technique found no differences up to 24 months.[9] Although disparate outcomes on knee

Table 5. Complications Over a 12-Month Period

	HRPR (n = 4)	Control (n = 8)	*P* Value
DVT/PE	1	0	
Superficial SSI	0	1	.11
Stiffness	1	0	
Re-rupture/revision	0	4	
Reoperation	2	0	
Delayed wound healing	0	1	
Cyclops lesion	0	2	
Complication rate	10%	12%	.75

NOTE. Alpha <0.05 denotes significance.

DVT, deep venous thrombosis; HRPR, Hybrid Remnant Preservation Reconstruction; PE, pulmonary embolism; SSI, surgical-site infection.

proprioception have been concluded, there are significant limitations in the literature. First, these previously reported literature on RP represents a conglomerate of techniques without standardization, therefore rendering it difficult to group and summarize these findings. Second, the available tools we have to assess proprioception are rather limited and may not reflect the dynamic nature of knee proprioception. The joint position sense or passive angle reproduction test described previously relies on a static measurement of the knee, which likely oversimplifies changes in knee kinematics and proprioception after ACL reconstruction. Further advances in these tools to assess proprioception will be required to answer these important questions.

Limitations

Our study has important limitations that must be acknowledged. The retrospective cohort design inherently limits our results in terms of lack of randomization, which may lead to selection bias, as well as loss to follow-up. Although we asked patients to return for regular clinical follow up at 1 year, 29.8% of patients did not follow-up and were unable to complete PROs at 1 year. These are key limitations of retrospective cohort studies for which patients are not prospectively followed and contacted to ensure follow-up. Moreover, we were unable to conduct 12-month performance testing of the entire cohort, which limits our conclusions regarding AP laxity, strength, and proprioception via timed hop testing, as we are underpowered to identify true differences between groups. The present results of HRPR are confined to 1-year outcomes and we were underpowered with 39 patients with HRPR compared to detect MCID for PROMIS-PF,[48] and may be too soon to determine the actual effect of this technique, as patients are either beginning or have initiated return to activities and play at a high level. Although all patients in the HRPR group had type 1 or 2 tears amenable for repair, we did not classify tears of the control group at the time of surgery or characterize whether remnant repair was fully approximated to the femoral wall or partially repaired.

Conclusions

ACL HRPR is associated with equivalent PROs, full ROM, and no differences in complications rates after 1 year compared with control patients in the present retrospective study.

Disclosure

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: J.P.C. reports other from Pinnacle and Skeletal Dynamics, outside the submitted work. V.M. reports personal fees from Pacira Pharmaceuticals, Inc.; nonfinancial support and other from Pinnacle; and other from Vericel Corp., Stryker, Smith & Nephew, and Arthrex, outside the submitted work. All other authors (M.A.G., E.L.H., J.B.) report no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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