Suture-Augmented ACL Repair for Proximal Avulsion or High-Grade Partial Tears Shows Similar Side-to-Side Difference and No Clinical Differences at Two Years Versus Conventional ACL Reconstruction for Mid-Substance Tears or Poor ACL Tissue Quality

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Purpose: To compare objective and subjective clinical outcomes between suture-augmented anterior cruciate ligament (ACL) repair (SAACLR) and conventional ACL reconstruction (CACLR) with minimum 2-year follow-up. **Methods:** In this nonrandomized, prospective study, 30 patients underwent SAACLR for proximal ACL avulsion or high-grade partial ACL tear (Sherman grade 1 or 2) and 30 patients underwent CACLR for proximal one-third/distal two-thirds junction tears and mid-substance tears (Sherman grade 3 or 4) tear types by 1 surgeon between 2018 and 2020. Failure was defined as ACL reinjury. Outcome measures were KT-1000 for side-to-side knee laxity evaluation, Visual Analog Scale for pain, International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Severity Score (KOOS), Tegner Activity Scale, Western Ontario and McMaster Universities Osteoarthritis Index, Lysholm Knee Scoring Scale, and Single Assessment Numeric Evaluation. Minimal clinically important difference (MCID) was calculated for IKDC and KOOS subscores. **Results:** Three failures (10%) occurred in the SAACLR group, with no failures in the CACLR group ($P = .24$). A total of 23 (85%) SAACLR patients and 27 (90%) CACLR patients had patient-reported outcomes and physical examination at minimum 2 years. Two-year KT-1000 testing with 20 lbs showed less than 1 mm side-to-side difference between the groups. No significant differences in the percentage of patients meeting the MCID were found between the SAACLR and CACLR groups at 2 years: IKDC, 10.81 (82%) versus 10.54 (93%) ($P = .48$); KOOS Pain, 11.55 (73%) versus 10.58 (78%) ($P = .94$); KOOS Symptoms, 8.15 (77%) versus 10.32 (74%) ($P = 1.0$); KOOS Activities of Daily Living, 12.19 (59%) versus 12.28 (70%) ($P = .60$); 18.99 (71%) versus 16.77 (86%) ($P = .42$). Significantly higher IKDC scores were observed with SAACLR versus CACLR at 3 months ($P = .01$) and 6 months ($P = .02$), and significantly higher Lysholm scale, Tegner Activity Scale, and all KOOS subscale scores were observed at 6 months. **Conclusions:** At 2 years after surgery, KT-1000 testing showed less than 1 mm side-to-side difference and no differences were observed between the groups in the percentage of patients who met or exceeded the MCID. Significantly higher early patient-reported outcome scores were found with SAACLR versus CACLR. The rerupture rate between the groups was not significantly different. **Level of Evidence:** Level II.

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Anterior cruciate ligament (ACL) tears are among the most debilitating injuries seen in athletes participating in pivoting and cutting sports, with an annual incidence of more than 120,000 cases per year in the United States.[1-3] Arthroscopic ACL reconstruction with autograft has become the gold standard treatment for ACL injuries in the athletic population. Many recent high-quality studies have shown overall excellent results with conventional ACL reconstruction (CACLR).[4,5] Despite advances in the understanding and treatment of ACL injuries over the last several decades, concerns remain around surgical morbidity, return to play in younger athletes, and high rates of new ACL injury after CACLR.[6-9]

Recently there has been a resurgent interest in ACL repair for proximal ACL tears based on promising results in small retrospective case series.[10-12] Compared with CACLR with autograft, this procedure involves less trauma to the knee by avoiding the step of graft harvest. With improved arthroscopic techniques, a better understanding of rehabilitation principles, and improved surgical materials, ACL repair has shown the potential to be a reliable treatment option in properly selected patients. However, there is very little high-quality evidence to support the use of modern-day ACL repair.

The purpose of this study was to compare objective and subjective clinical outcomes between suture-augmented anterior cruciate ligament repair (SAACLR) and CACLR with minimum 2-year follow-up. We hypothesized that there would be no significant difference in KT-1000 measurements between the operative and nonoperative knee in the SAACLR group and that there would be no difference between the groups in patient-reported outcomes (PROs) at minimum 2-year follow-up. We also hypothesized that early functional results would be significantly better in patients undergoing SAACLR compared to CACLR.

Methods

Study Population

After institutional review board (IRB) approval (MedStar Health Research Institute IRB study 00000048), a total of 60 consecutive patients with ACL injuries were prospectively identified in clinic between March 2018 and January 2020. After determination of the need for operative treatment, informed consent was obtained from each patient or the designated decision-maker for minor patients. Inclusion criteria were age 14 years and older and clinical and magnetic resonance imaging confirmation of ACL rupture. All patients were skeletally mature at the time of surgery. Patients were excluded if they had previously undergone ipsilateral or contralateral ACL surgery and if they had concomitant ipsilateral ligamentous knee injury or pre-existing osteoarthritis of the injured knee. Surgical consent was obtained for SAACLR and CACLR. All surgeries were performed by the senior author (W.A.D). The decision regarding which procedure the patient underwent was determined by diagnostic arthroscopy during surgery based on tear location, quantified as the distance of the tear from the femoral origin relative to the tibial footprint expressed as a percentage.[13] Thirty patients with femoral avulsion or proximal tear of the ACL (Sherman grade 1 or 2) or a symptomatic high-grade partial tear underwent SAACLR. Thirty patients with a tear with greater than 20% of the ligament remaining on the femoral origin (Sherman grade 3) or mid-substance tears (Sherman grade 4) underwent CACLR. Failure was defined as ACL reinjury.

Intervention

SAACLR was performed with the InternalBrace device (Arthrex, Inc, Naples, FL) based on techniques described previously.[12,14,15] The ACL remnant was whipstitched with a no. 2 nonabsorbable suture (FiberLink; Arthrex, Inc.) using a suture passer. Femoral and tibial tunnels (3.5-mm diameter) were drilled through the anatomic femoral and tibial ACL footprints. A suture augmentation and suture button construct was created on the back table by passing a high-tensile—strength braided suture (FiberTape; Arthrex, Inc.) through the loop of a reverse tensioning cortical ACL button (TightRope RT; Arthrex, Inc.). The suture augmentation construct was passed through the tibial and femoral tunnels. The suture button was then passed through the lateral femur along with the free end of the ACL repair suture. After the button was secured against the lateral femoral cortex, a 4.75-mm knotless suture anchor (SwiveLock; Arthrex, Inc.) was used to secure the distal limbs of the suture augmentation and suture button construct to the tibial cortex just distal to the tibial tunnel. The construct was tensioned in full knee extension, and the ACL repair suture was then tied to a suture embedded in the lateral cortical button. CACLR was performed with patellar tendon autograft, quadriceps tendon autograft, or allograft based on a shared decision model, with patellar tendon autograft preferred in skeletally mature pivoting and cutting athletes under age 30. Both CACLR techniques were performed arthroscopically, drilling the femoral socket through an accessory anteromedial portal. Patellar tendon autograft reconstruction was performed with an interference screw technique, retrograde drilling a full tibial tunnel. Quadriceps autograft and allograft techniques were performed with all-soft tissue grafts, drilling retrograde tibial sockets and using an adjustable loop and suspensory cortical buttons for definitive fixation on both

the lateral femoral cortex and anteromedial tibial cortex.

All patients were instructed to be weightbearing as tolerated after surgery and underwent a milestone-based rehabilitation protocol beginning within 1 week of surgery. Early rehabilitation was focused on range of motion, edema control, and initiation of major muscle firing patterns. Rehabilitation then progressed through increasingly demanding functional tasks after successful completion of lesser tasks without pain or complaint of subjective instability. Crutches were discontinued at 10 to 14 days. A reduced weight jogging program was begun as tolerated at 3 months. The goal for return to full unrestricted activity was 9 to 12 months. Return to play decisions were made using a shared decision model, which included objective functional return to play testing.

Data Collection

Patients were followed up prospectively and underwent clinic evaluations before and after surgery at 2 weeks, 6 weeks, 3 months, 6 months, 1 year, and minimum 2 years. Patients filled out PRO forms online using the Surgical Outcomes System database (Arthrex, Inc.), a web-based platform for collecting PROs.

The study design followed Panther Symposium ACL Treatment Consensus Group guidelines for high-quality clinical studies involving ACL outcomes.[16] All patients underwent preoperative and postoperative arthrometric side-to-side knee laxity evaluation with the KT-1000 knee arthrometer (MEDmetric Corp, San Diego, CA). Patients completed online PRO surveys at each study timepoint, including Visual Analog Scale (VAS) for pain, International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Severity Score (KOOS), Tegner Activity Scale, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Lysholm Knee Scoring Scale, and Single Assessment Numeric Evaluation (SANE). Return to sport or activity level were self-reported by patients.

Statistical Analysis

Data exported from the Surgical Outcomes System database were analyzed using R software (version 4.1.2) for statistical comparison. A priori power analysis was based on the primary outcome of knee laxity as measured by arthrometry. Based on studies that report a mean difference in knee laxity between ACL torn and unaffected knees of 5.3 mm $\pm$ standard deviation 2.6 mm,[17,18] a difference of <3 mm in knee laxity between injured and healthy knees was considered to indicate clinical success.[19] For calculations, 2.3 mm was used as a conservative estimate of effect size. Significance level was set to .95 and power to 80%. It was determined that a minimum of 16 subjects per group was necessary to detect an effect size of 2.3 mm with a power of 80%. We enrolled 30 subjects in each group. Values of PRO scores were compared between the 2 groups at each timepoint. KT-1000 data were converted for analysis from millimeters to side-to-side difference by subtracting the value of the uninvolved knee from the involved (injured) knee. Two-tailed unpaired *t*-test, Welch's unequal variances *t*-test, and Wilcoxon rank-sum test were used to compare the groups. One-tailed paired *t*-test and Wilcoxon signed-rank tests were used to compare preoperative to 2-year postoperative data within the groups. Normality tests and tests for equality of variances were conducted to determine whether a parametric or nonparametric test should be used.

Table 1. Baseline Patient Demographics

Factor	Repair (n = 30)	Reconstruction (n = 30)	*P* Value
Sex			.80
Male	13 (43.3%)	14 (46.7%)	
Female	17 (56.7%)	16 (53.3%)	
Age (yr)	27.5 (18-37)	25.5 (17-33)	.56
Injured Side			.44
Left	16 (53.3%)	13 (43.3%)	
Right	14 (46.7%)	17 (56.7%)	
Body mass index, mean (range)	25.3 (23.8-28.3)	24.2 (22.6-26.4)	.04*
Level of sport competition			.69
Professional/Semiprofessional	0 (0%)	2 (6.7%)	
Collegiate	1 (3.3%)	2 (6.7%)	
Recreational	16 (53.3%)	16 (53.3%)	
High School	6 (20.0%)	4 (13.3%)	
Work-related	2 (6.7%)	1 (3.3%)	
Other/not reported	5 (16.7%)	5 (16.7%)	

*Significant difference ($P < .05$).

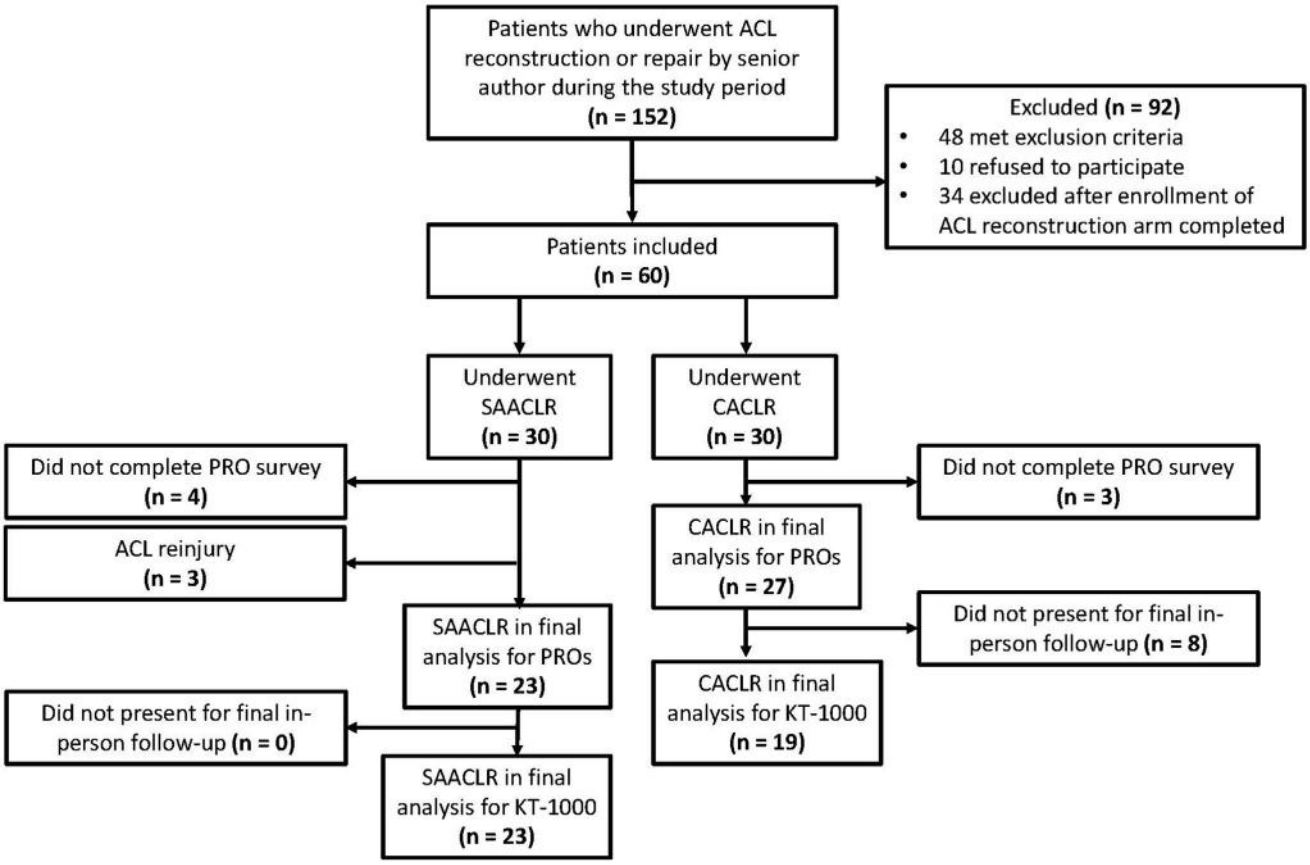

Fig 1. Flow diagram of inclusion and exclusion of patients in study. ACL, anterior cruciate ligament; SAACLR, suture-augmented anterior cruciate ligament repair; CACLR, conventional anterior cruciate ligament reconstruction; PRO, patient-reported outcome.

Pearson's χ^2 test was used to compare categorical variables. P values $<.05$ were considered statistically significant.

The minimal clinically important difference (MCID) was calculated using the distribution-based method[20] with ½ standard deviation for IKDC and KOOS scores. MCID results were reported as a percentage of patients in each group who met or exceeded the MCID.

Results

There were no demographic differences between groups except for higher body mass index in the SAACLR group (Table 1). There were three failures (10%) in the SAACLR group and no failures in the CACLR group ($P = .24$). Of the 27 remaining SAACLR patients, 23 (85%) had minimum 2-year follow-up for PROs and underwent history, physical examination, and KT-1000 arthrometric evaluation (Fig 1). Of the 30 patients in the CACLR group, 13 received bone-patellar tendon-bone (BPTB) autograft and 17 received quadriceps tendon autograft at the time of reconstruction. Of these 30 patients, 27 (90%) had minimum 2-year follow-up for PROs, and 19 (63%) underwent physical examination (Fig 1). One patient in the CACLR

Table 2. Side-to-Side KT-1000 Arthrometer Data*

	Preoperative Data, mm (Mean ± SD)			Postoperative Data, mm (mean ± SD)					
				1 Year			2 Years		
Applied force	SAACLR (n = 23)	CACLR (n = 19)	*P* Value	SAACLR (n = 23)	CACLR (n = 19)	*P* Value	SAACLR (n = 23)	CACLR (n = 19)	*P* Value
15 lbs	1.78 ± 1.22	1.67 ± 0.71	.78	0.58 ± 0.79	0.47 ± 1.33	.46	0.33 ± 1.03	−0.22 ± 0.88	.084
20 lbs	2.28 ± 1.32	2.22 ± 0.97	.98	0.42 ± 0.67	0.41 ± 1.37	.64	0.39 ± 0.98	−0.33 ± 0.97	.034

*Difference calculated by subtracting the value obtained from the uninjured knee from that of the injured knee.

Table 3. MCID for Patient-Reported Outcome Measures at 2 Years

	Suture Augmented ACL Repair		Conventional ACL Reconstruction		
	MCID Value*	Percentage met or exceeded MCID	MCID Value*	Percentage met or exceeded MCID	*P* Value SAACLR Versus CACLR
IKDC	10.81	82% (18/22)	10.54	93% (25/27)	.48
KOOS Pain	11.55	73% (16/22)	10.58	78% (21/27)	.94
KOOS Symptoms	8.15	77% (17/22)	10.32	74% (20/27)	1.0
KOOS ADL	12.19	59% (13/22)	12.58	70% (19/27)	.60
KOOS Sport and Recreation	18.99	71% (12/17)	16.77	86% (19/22)	.42

ACL, anterior cruciate ligament; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Severity Score; MCID, Minimal Clinically Important Difference.
*MCID calculation method: distribution-based method using ½ standard deviation.

group complained of continued pain and subjective instability and reported inability to return to athletic activity.

The 3 SAACLR patients who failed underwent revision to CACLR. Average age at failure was 19.6 (range 15-26) years, and reinjury occurred during high school, collegiate, or recreational athletic competition. The first patient returned to full competition as a collegiate volleyball player at 10 months after surgery. She reinjured the knee playing volleyball 17 months after surgery and underwent revision to CACLR with BPTB autograft and lateral meniscal root repair. The second patient reinjured the knee while playing Olympic development scholastic soccer 11 months after surgery and underwent revision to CACLR with BPTB autograft and medial meniscus repair. The third patient reinjured the knee while playing competitive recreational soccer 12 months after surgery in his first game back and underwent revision to CACLR with quadriceps tendon autograft.

Side-to-side KT-1000 arthrometer data at 15 lbs and 20 lbs of force at final follow-up are shown in Table 2. There was no significant difference in measurements with 15 lbs of force between the repair and reconstruction groups (0.33 ± 1.03 mm and −0.22 ± 0.88 mm, respectively; $P = .08$). A significant difference of less than 1 mm was observed between the repair and reconstruction groups with 20 lbs of force (0.39 ± 0.98 mm and −0.33 ± 0.97 mm, respectively; $P = .03$).

No significant differences were found between the SAACLR and CACLR groups in the percentage of patients who met or exceeded the MCID at 2 years: IKDC, 10.81 (82%) versus 10.54 (93%) ($P = .48$); KOOS Pain, 11.55 (73%) versus 10.58 (78%) ($P = .94$); KOOS Symptoms, 8.15 (77%) versus 10.32 (74%) ($P = 1.0$); KOOS Activities of Daily Living (ADL) 12.19 (59%) versus 12.28 (70%) ($P = .60$); 18.99 (71%) versus 16.77 (86%) ($P = .42$) (Table 3).

Patients in both groups exhibited statistically significant improvements in all PROs at 2 years after surgery compared with before surgery (Table 4). Patients who underwent SAACLR had significantly higher preoperative KOOS ADL and WOMAC function scores compared to patients undergoing CACLR (Table 5). IKDC scores were significantly higher in the SAACLR group compared to the CACLR group at 3 and 6 months after surgery, with no difference at 1 or 2 years (Table 5, Fig 2). At 6 months after surgery, patients undergoing SAACLR had significantly higher scores on the Lysholm scale, Tegner Activity Scale, and each of the KOOS subscales compared with the CACLR group, with no differences noted at 2 years (Table 5, Figs 3 and 4). No significant difference in VAS pain or SANE scores were observed at any timepoint.

Return to play data at 2 years was available in 26/30 patients in the SAACLR group and 25/30 patients in the CACLR group. Rate of return to play was 57.7% (median 9.2 months, range 21-112 weeks) after SAACLR and 64.0% (median 11.7 months, range 40-104 weeks) after CACLR.

Discussion

In this study, 3 failures occurred in patients undergoing SAACLR, and no failures were observed in patients undergoing CACLR. The reinjury rate after SAACLR was consistent with previous reports.[11,12,21-25] However, this difference was not statistically significant. KT-1000 testing at 2 years with 20 lbs showed less than 1 mm side-to-side difference between the groups. No difference was observed between the groups in the percentage of patients who met or exceeded the MCID at 2 years. Patients undergoing SAACLR had significantly higher scores in multiple PROs at 3 and 6 months after surgery compared to CACLR, which might suggest better early functional outcomes with SAACLR. Our findings with respect to early functional outcome in SAACLR patients may reflect the benefit of avoiding donor site morbidity with graft harvest[26,27] and retained proprioception by avoiding graft harvest and ligament replacement.[11,12,21-25]

Table 4. Patient-Reported Outcomes Comparing Preoperative Versus 2-Year Postoperative Timepoints for SAACLR and CACLR

	Preoperative Versus Postoperative Data, Mean ± SD; Median [IQR]; (n)					
	Suture Augmented ACL Repair			Conventional ACL Reconstruction		
Test	Preoperative	2 years Postoperative	*P* Value	Preoperative	2 Years Postoperative	*P* Value
IKDC	49.5 ± 21.5; 48.3 [39.1-56.3]; (29)	85.4 ± 13.4; 90.8 [78.8-95.5]; (23)	<.001*	40.0 ± 18.5; 39.1 [25.3-50.0]; (30)	84.5 ± 14.1; 88.5 [77.6-94.9]; (27)	<.001*
KOOS Pain	67.9 ± 23.1; 69.4 [52.8-86.1]; (29)	93.8 ± 6.3; 93.8 [91.7-100.0]; (23)	<.001*	60.4 ± 21.4; 58.3 [47.2-76.4]; (30)	91.2 ± 10.6; 91.7 [88.9-97.2]; (27)	<.001*
KOOS Symptoms	65.8 ± 19.9; 64.3 [53.6-82.1]; (29)	87.1 ± 10.5; 85.7 [82.1-94.6]; (23)	<.001*	55.8 ± 18.6; 53.6 [46.4-69.6]; (30)	82.3 ± 15.7; 85.7 [75.0-92.9]; (27)	<.001*
KOOS ADL	73.5 ± 24.9; 83.4 [50.0-94.1]; (29)	97.3 ± 4.70; 100.0 [96.3-100.0]; (23)	<.001*	62.6 ± 25.2; 67.7 [43.4-84.9]; (30)	96.8 ± 7.4; 100.0 [96.3-100.0]; (27)	<.001*
KOOS Sport/Rec	33.4 ± 35.2; 17.5 [1.3-61.9]; (26)	83.0 ± 19.2; 90.0 [75.0-95.0]; (21)	<.001*	17.4 ± 19.1; 15.0 [0.0-25.0]; (25)	83.3 ± 20.7; 90.0 [81.3-95.0]; (26)	<.001*
KOOS QoL	31.3 ± 24.1; 25.0 [18.8-43.8]; (29)	70.9 ± 21.5; 75.0 [62.5-87.5]; (23)	<.001*	22.5 ± 16.5; 21.9 [12.5-31.3]; (30)	71.8 ± 22.4; 75.0 [56.3-90.6]; (27)	<.001*
VAS Pain	3.0 ± 2.5; 2.5 [1.1-4.7]; (30)	1.0 ± 1.5; 0.1 [0.0-1.8]; (23)	<.001*	2.6 ± 2.3; 2.1 [1.0-3.8]; (30)	1.1 ± 1.9; 0.2 [0.0-1.8]; (27)	<.001*
SANE	51.2 ± 29.4; 50.5 [31.0-74.8]; (30)	90.6 ± 11.1; 92.0 [87.0-99.0]; (23)	<.001*	42.9 ± 19.1; 41.0 [32.3-51.0]; (30)	87.0 ± 18.8; 90.0 [84.0-99.0]; (27)	<.001*
Tegner	3.9 ± 2.9; 3.0 [2.0-6.0]; (29)	6.0 ± 2.6; 5.0 [4.0-8.5]; (23)	.0041*	2.9 ± 3.3; 2.0 [1.0-3.0]; (30)	5.9 ± 1.9; 6.0 [5.0-7.0]; (27)	<.001*
Lysholm	52.7 ± 24.6; 53.0 [33.0-69.0]; (29)	87.8 ± 12.5; 90.0 [83.0-100.0]; (23)	<.001*	49.0 ± 23.9; 44.0 [29.3-66.0]; (30)	87.6 ± 13.4; 91.0 [83.0-95.0]; (27)	<.001*
WOMAC Pain	76.0 ± 23.1; 80.0 [60.0-95.0]; (29)	98.3 ± 3.2; 100.0 [97.5-100.0]; (23)	<.001*	71.5 ± 21.6; 77.5 [51.3-88.8]; (30)	96.7 ± 6.5; 100.0 [95.0-100.0]; (27)	<.001*
WOMAC Function	73.5 ± 24.9; 82.5 [50.0-94.1]; (29)	97.3 ± 4.7; 100.0 [96.3-100.0]; (23)	<.001*	62.6 ± 25.2; 67.7 [43.4-84.9]; (30)	96.8 ± 7.44; 100.0 [96.3-100.0]; (27)	<.001*
WOMAC Stiffness	66.0 ± 27.3; 62.5 [50.0-87.5]; (29)	85.9 ± 16.6; 87.5 [75.0-100.0]; (23)	<.001*	56.3 ± 25.4; 62.5 [40.6-75.0]; (30)	82.4 ± 17.8; 87.5 [75.0-100.0]; (27)	<.001*

IKDC, International Knee Documentation Committee; IQR, interquartile range; KOOS, Knee Osteoarthritis Outcome Score; ADL, Activities of Daily Living; QoL, Quality of Life; SANE, Single Assessment Numeric Evaluation; VAS, Visual Analog Scale.

*Significant difference ($P < .05$).

Table 5. Patient-Reported Outcomes Comparing SAACLR Versus CACLR

	Preoperative Versus Postoperative PRO Data, Mean ± SD; Median [IQR]; (n)														
	Preoperative			Postoperative											
				3 months			6 months			1 year			2 years		
Test	SAACLR	CACLR	*P* Value	SAACLR	CACLR	*P* Value	SAACLR	CACLR	*P* Value	SAACLR	CACLR	*P* Value	SAACLR	CACLR	*P* Value
IKDC	49.5 ± 21.5; 48.3 [39.1-56.3]; (29)	40.0 ± 18.5; 39.1 [25.3-50.0]; (30)	.07	63.4 ± 10.9; 61.5 [55.8-74.4]; (26)	53.4 ± 14.1; 54.0 [45.7-60.1]; (28)	.01*	75.7 ± 14.3; 74.8 [65.0-85.1]; (26)	65.0 ± 17.1; 62.1 [53.7-75.3]; (28)	.02*	85.6 ± 13.4; 89.7 [80.5-95.4]; (25)	79.0 ± 14.5; 80.5 [70.7-90.9]; (27)	.06	85.4 ± 13.4; 90.8 [78.8-95.5]; (23)	84.5 ± 14.1; 88.5 [77.6-94.9]; (27)	.70
KOOS Pain	67.9 ± 23.1; 67.9 [52.8-86.1]; (29)	60.4 ± 21.4; 58.3 [47.2-76.4]; (30)	.20	81.4 ± 10.9; 80.6 [75.0-91.7]; (26)	77.1 ± 13.1; 76.4 [66.7-84.7]; (28)	.25	88.3 ± 12.3; 91.7 [84.0-96.5]; (26)	79.5 ± 15.7; 80.6 [66.7-91.7]; (28)	.03*	93.3 ± 10.6; 93.3 [86.1-100.0]; (25)	89.0 ± 9.4; 88.9 [84.7-97.2]; (27)	.01*	93.8 ± 6.3; 94.4 [91.7-100.0]; (23)	91.2 ± 10.6; 91.7 [88.9-97.2]; (27)	.28
KOOS Symptoms	65.8 ± 19.9; 64.3 [53.6-82.1]; (29)	55.8 ± 18.6; 53.6 [46.4-69.6]; (30)	.05	74.3 ± 10.6; 75.0 [67.9-82.1]; (26)	68.1 ± 15.9; 66.1 [56.3-78.6]; (28)	.10	83.4 ± 11.0; 85.7 [78.6-89.3]; (26)	72.6 ± 16.4; 75.0 [64.3-82.1]; (28)	.01*	86.7 ± 10.8; 89.3 [82.1-92.9]; (25)	81.1 ± 12.4; 82.1 [71.4-91.1]; (27)	.088	87.1 ± 10.5; 85.7 [82.1-94.6]; (23)	82.3 ± 15.7; 85.7 [75.0-92.9]; (27)	.31
KOOS ADL	73.5 ± 24.9; 83.4 [50.0-94.1]; (29)	62.6 ± 25.2; 67.7 [43.4-62.6]; (30)	.04*	89.6 ± 8.1; 91.2 [82.4-95.6]; (26)	83.8 ± 14.2; 89.7 [75.4-94.1]; (28)	.19	94.3 ± 10.4; 99.3 [94.5-100.0]; (26)	88.1 ± 13.6; 94.1 [81.6-97.1]; (28)	.01*	97.2 ± 7.2; 100.0 [98.5-100.0]; (25)	96.4 ± 6.14; 98.5 [97.1-100.0]; (27)	.05	97.3 ± 4.7; 100.0 [96.3-100.0]; (23)	96.8 ± 7.4; 100.0 [96.3-100.0]; (27)	.87
KOOS Sport/ Rec	33.4 ± 35.2; 17.5 [1.3-61.9]; (26)	17.4 ± 19.1; 15.0 [0.0-25.0]; (25)	.27	60.5 ± 22.4; 58.3 [46.9-77.5]; (23)	40.8 ± 30.1; 40.0 [17.5-60.8]; (23)	.02*	75.9 ± 22.0; 77.5 [65.0-94.7]; (26)	58.8 ± 26.0; 58.3 [40.0-75.0]; (25)	.02*	89.4 ± 12.6; 95.0 [81.7-100.0]; (23)	79.3 ± 16.7; 80.0 [70.0-94.4]; (27)	.02*	83.0 ± 19.2; 90.0 [75.0-95.0]; (21)	83.3 ± 20.7; 90.0 [81.3-95.0]; (26)	.95
KOOS QoL	31.3 ± 24.1; 25.0 [18.8-43.8]; (29)	22.5 ± 16.5; 21.9 [12.5-31.3]; (30)	.18	45.4 ± 16.0; 43.8 [37.5-54.7]; (26)	43.8 ± 16.0; 43.8 [31.3-56.3]; (28)	.58	63.5 ± 19.5; 59.4 [50.0-75.0]; (26)	49.6 ± 22.7; 46.9 [37.5-57.8]; (28)	.02*	74.3 ± 19.3; 75.0 [62.5-87.5]; (25)	62.7 ± 20.0; 62.5 [50.0-75.0]; (27)	.04*	70.9 ± 21.5; 75.0 [62.5-87.5]; (23)	71.8 ± 22.4; 75.0 [56.3-90.6]; (27)	.89
VAS Pain	3.0 ± 2.5; 2.5 [1.1-4.7]; (30)	2.6 ± 2.3; 2.1 [1.0-3.8]; (30)	.62	1.2 ± 1.2; 1.0 [0.0-1.9]; (27)	1.4 ± 1.4; 1.0 [0.1-2.0]; (28)	.64	1.2 ± 2.0; 0.2 [0.0-1.4]; (26)	1.4 ± 1.8; 0.8 [0.0-2.0]; (29)	.56	0.9 ± 1.6; 0.2 [0.0-1.0]; (25)	1.0 ± 1.5; 0.2 [0.0-1.1]; (27)	.95	1.0 ± 1.5; 0.1 [0.0-1.8]; (23)	1.1 ± 1.9; 0.2 [0.0-1.8]; (27)	.83
SANE	51.2 ± 29.4; 50.5 [31.0-74.8]; (30)	42.9 ± 19.1; 41.0 [32.3-51.0]; (30)	.20	65.5 ± 20.9; 70.0 [52.5-80.8]; (26)	64.1 ± 20.6; 66.5 [49.3-80.3]; (28)	.74	77.4 ± 15.9; 79.0 [72.5-85.5]; (26)	73.6 ± 21.2; 79.0 [66.0-90.0]; (29)	.83	81.2 ± 26.9; 90.0 [85.0-95.0]; (25)	82.4 ± 17.5; 86.0 [82.0-94.5] (27)	.43	90.6 ± 11.1; 92.0 [87.0-99.0]; (23)	87.0 ± 18.8; 90.0 [84.0-99.0]; (27)	.70
Tegner	3.9 ± 2.9; 3.0 [2.0-6.0]; (29)	2.9 ± 3.3; 2.0 [1.0-3.0]; (30)	.07	3.0 ± 1.5; 3.0 [2.0-3.0]; (26)	2.4 ± 1.2; 2.0 [2.0-3.0]; (28)	.11	5.0 ± 2.0; 4.0 [4.0-6.0]; (26)	3.7 ± 1.9; 3.0 [2.8-5.0]; (28)	.01*	5.8 ± 2.2; 5.0 [5.0-7.0]; (25)	5.8 ± 2.2; 6.0 [4.0-7.0]; (27)	.90	6.0 ± 2.6; 5.0 [4.0-8.5]; (23)	5.9 ± 1.9; 6.0 [5.0-7.0]; (27)	.71
Lysholm	52.7 ± 24.6; 53.0 [33.0-69.0]; (29)	49.0 ± 23.9; 44.0 [29.3-66.0]; (30)	.48	76.1 ± 12.1; 80.0 [67.8-84.8]; (26)	72.4 ± 16.1; 70.5 [61.5-85.3]; (28)	.35	86.2 ± 12.1; 88.5 [81.5-95.0]; (26)	78.1 ± 15.3; 78.0 [69.8-88.5]; (28)	.03*	89.4 ± 14.8; 95.0 [86.0-100.0]; (25)	85.2 ± 12.7; 87.0 [78.0-94.0]; (27)	.06	87.8 ± 12.5; 90.0 [83.0-100.0]; (23)	87.6 ± 13.4; 91.0 [83.0-95.0]; (27)	.91
WOMAC Pain	76.0 ± 23.1; 80.0 [60.0-95.0]; (29)	71.5 ± 21.6; 77.5 [51.3-88.8]; (30)	.30	90.4 ± 9.5; 95.0 [85.0-100.0]; (26)	85.5 ± 13.1; 90.0 [80.0-95.0]; (28)	.17	92.5 ± 11.9; 95.0 [95.0-100.0]; (26)	87.5 ± 13.0; 90.0 [80.0-100.0]; (28)	.08	96.8 ± 7.9; 100.0 [100.0-100.0]; (25)	95.9 ± 6.2; 95.0 [95.0-100.0]; (27)	.06	98.3 ± 3.2; 100.0 [97.5-100.0]; (23)	96.7 ± 6.5; 100.0 [95.0-100.0]; (27)	.41
WOMAC Function	73.5 ± 24.9; 82.4 [50.0-94.1]; (29)	62.6 ± 25.2; 67.7 [43.4-84.9]; (30)	.04*	89.6 ± 8.1; 91.2 [82.4-95.6]; (26)	83.8 ± 14.2; 89.7 [75.4-94.1]; (28)	.19	94.3 ± 10.4; 99.3 [94.5-100.0]; (26)	88.1 ± 13.6; 94.1 [81.6-97.1]; (28)	.01*	97.2 ± 7.2; 100.0 [98.5-100.0] (25)	96.4 ± 6.2; 98.5 [97.1-100.0]; (27)	.05	97.3 ± 4.7; 100.0 [96.3-100.0]; (23)	96.8 ± 7.44; 100.0 [96.3-100.0]; (27)	.865
WOMAC Stiffness	66.0 ± 27.3; 62.5 [50.0-87.5]; (29)	56.3 ± 25.4; 62.5 [40.6-75.0]; (30)	.16	72.6 ± 12.3; 75.0 [62.5-75.0]; (26)	63.0 ± 21.9; 62.5 [50.0-75.0]; (28)	.07	82.7 ± 18.4; 87.5 [75.0-100.0]; (26)	66.5 ± 22.1; 62.5 [50.0-78.1]; (28)	.01*	87.5 ± 14.0; 87.5 [75.0-100.0]; (25)	80.6 ± 12.2; 75.0 [75.0-87.5]; (27)	.04*	85.9 ± 16.6; 87.5 [75.0-100.0]; (23)	82.4 ± 17.8; 87.5 [75.0-100.0]; (27)	.48

PRO, patient-reported outcomes; SD, standard deviation; IKDC, International Knee Documentation Committee; IQR, interquartile range; KOOS, Knee Osteoarthritis Outcome Score; ADL, Activities of Daily Living; QoL, Quality of Life; SANE, Single Assessment Numeric Evaluation; VAS, Visual Analog Scale.

*Significant difference ($P < .05$).

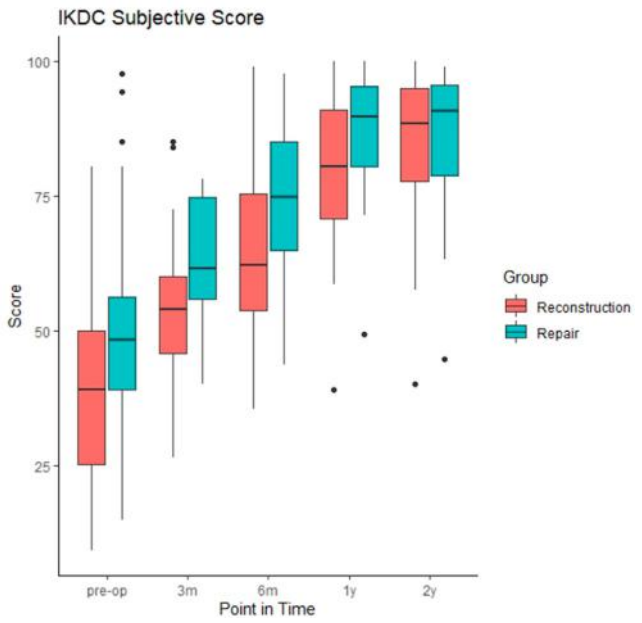

Fig 2. Box plot comparison of International Knee Documentation Committee (IKDC) scores between suture augmented ACL repair (SAACLR) and conventional ACL reconstruction (CALCR). The repair group demonstrated significantly higher IKDC scores compared to the reconstruction group at 3 months (63.4 ± SD 10.9; 61.5 [interquartile range {IQR} 55.8-74.4] vs 53.4 ± 14.1; 54.0 [IQR 45.7-60.1]; $P = .01$) and 6 months (75.7 ± 14.3; 74.8 [IQR 65.0-85.1] vs 65.0 ± 17.1; 62.1 [IQR 53.7-75.3]; $P = .02$), with no differences at 1 or 2 years.

A significant difference in side-to-side KT-1000 measurements was observed at 2 years after surgery. However, the difference of less than 1 mm was well below the side-to-side difference of 3 mm previously reported to represent a clinically significant difference in knee laxity.[17]A side-to-side difference of less than 3 mm is thought to represent unimpaired anterior tibial translation,[17] and a difference of greater than 5 mm has been considered to indicate postoperative failure of the graft as an anteroposterior restraint.[28,29] Our findings suggest that knee stability is maintained after surgery with both procedures and does not differ based on procedure.

Although no difference in VAS pain or WOMAC pain scores was observed between the groups at any timepoint, KOOS Pain subscores were significantly higher with SAACLR compared with CACLR at 6 months and 1 year, possibly reflecting donor site morbidity and anterior knee pain after graft harvest for CACLR. One study reported that 13.9% of 200 patients still had anterior knee pain with activity at 2-year follow-up after ACL reconstruction with BPTB autograft.[26] A meta-analysis comparing ACL autograft types found anterior knee pain in 17.4% of 972 patients treated with BPTB autograft and in 11.5% of 390 patients treated with hamstring tendon autograft.[27] However, not all pain scores reflected a difference between the groups, suggesting that factors other than pain, such as retained proprioception and minimal soft tissue disruption, may contribute to earlier restoration of function after SAACLR. Patients undergoing ACL repair have recently been shown to have less daily awareness of their operated knee compared to ACL reconstruction.[22]

The current findings are consistent with previous reports of SAACLR. In one study, 23 of 27 patients had no clinical instability or subjective complaints at 2-year follow-up.[12] Four (14.8%) patients in that series sustained a recurrent ACL injury requiring revision to reconstruction. In the 11 patients with available baseline data, significant improvements in the KOOS composite score met or exceeded the MCID. Hopper et al.[24] found satisfactory PROs in 28 out of 34 patients (82.4%) at a minimum of 5 years follow-up after primary ACL repair with suture tape augmentation for proximal ACL tears. Six of these 34 patients (17.6%) sustained an ACL re-rupture after repair. Burton et al.[11] reported a failure rate of only two out of 29 patients (6.9%) undergoing ACL repair with a minimum of 2-year follow-up. Vermeijden et al.[23] found that in 60 patients undergoing primary ACL repair, 85% returned to sport at an average of 180 days after surgery. In another retrospective case series, of 56 patients

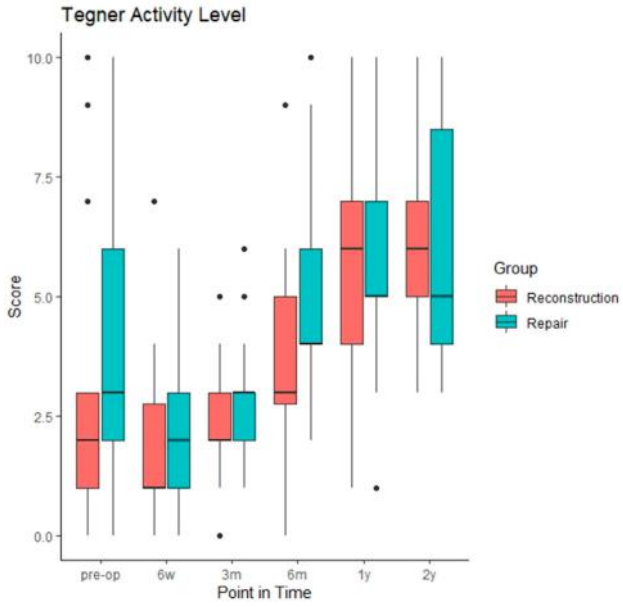

Fig 3. Box plot comparison of Tegner Activity Scale scores between suture augmented ACL repair (SAACLR) and conventional ACL reconstruction (CALCR). The repair group demonstrated significantly higher Tegner Activity Scale scores (5.0 ± 2.0; 4.0 [interquartile range {IQR} 4.0-6.0] vs 3.7 ± 1.9; 3.0 [IQR 2.8-5.0], $P = .01$) compared to the reconstruction group at 6 months, with no differences at other timepoints.

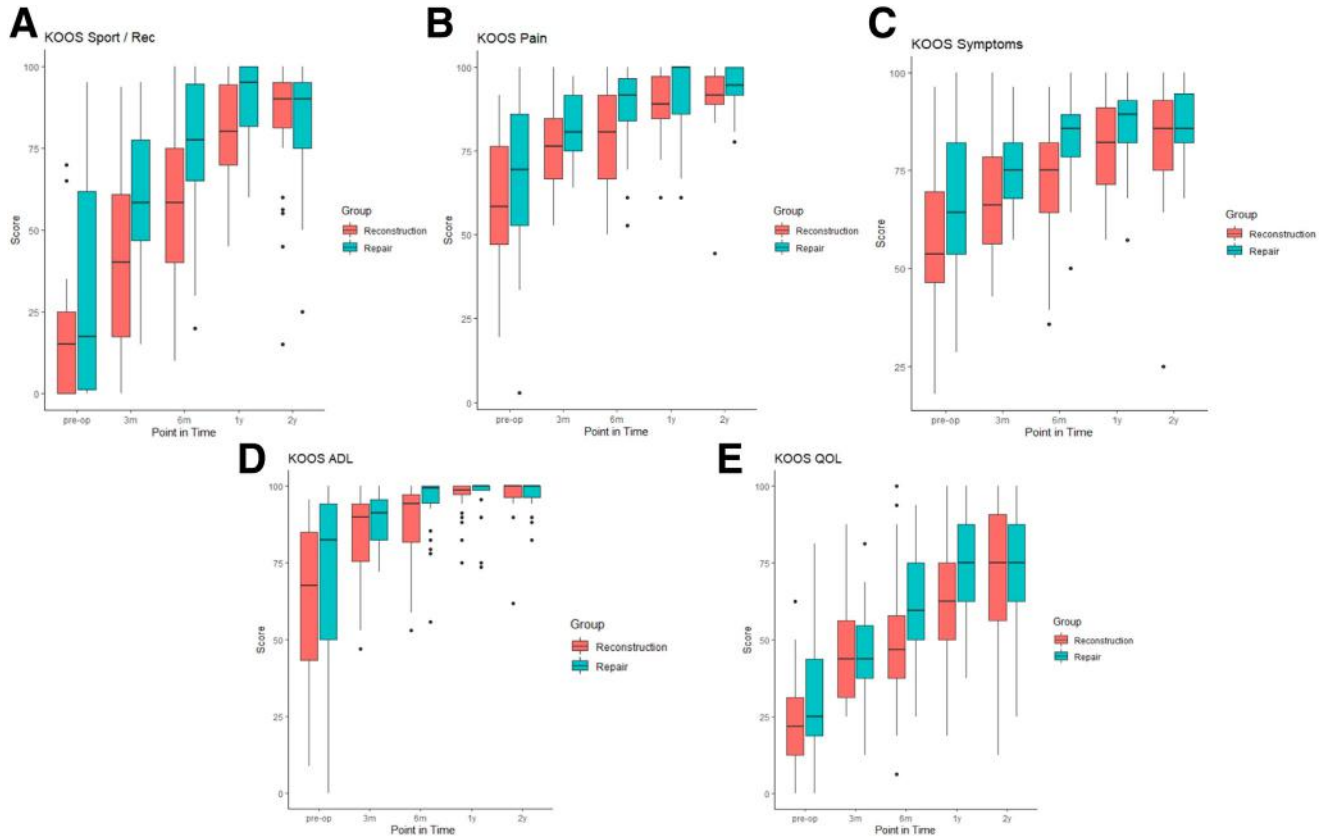

Fig 4. Box plot comparisons of Knee Osteoarthritis Outcome Score (KOOS) subscores between SAACLR and conventional ACL reconstruction. The repair group demonstrated statistically significantly greater subscores at 3 months for KOOS Sport/Rec (A); greater subscores at 6 months for KOOS Sport/Rec (A), Pain (B), Symptoms (C), ADL (D), and QoL (E); greater subscores at 1 year for Sport/Rec (A), Pain (B), and ADL (D); and no significant differences at 2 years after surgery. Sport/Rec, sport/recreation; ADL, activities of daily living; QoL, quality of life.

undergoing primary ACL repair, 6 repairs (10.7%) failed, and 4 additional patients underwent reoperation (7.1%), 2 for meniscus tears and 2 for suture anchor irritation.[25] Failure rates were 7.4% and 13.8% with and without internal bracing, respectively ($P = .672$). There were no statistically significant or clinically relevant differences in subjective outcomes.

Limitations

Limitations of this study include lack of standardization of CACLR type and lack of blinding. The decision to proceed with repair over reconstruction occurred intraoperatively based on observation of tear characteristics during diagnostic arthroscopy. It cannot be assumed that the conditions that result in proximal avulsion injury are the same as those that lead to intrasubstance tear. Moreover, it would have been standard to recommend to all patients in the study that they undergo CACLR based on clinical and radiologic findings. Non-standardization of the CACLR group to one graft type (e.g., patellar tendon autograft) is another major weakness of our study. Homogeneity in patient outcomes between CACLR graft types cannot be assumed. Although these differences reflect real-life shared decision algorithms in the senior author's practice, the different graft types could have confounded potential comparisons between SAACLR and CACLR in our study. Assignment to one group or the other was based on existing criteria for use of SAACLR[12,13] and allowed for comparison of SAACLR and CACLR at multiple timepoints during the study. This study was limited to minimum 2-year follow-up. Two-year data are important for understanding outcomes related to return to activity, but they do not provide insight into long-term viability of the procedure. Longer follow-up is needed to assess risk and outcomes of new ACL injury after SAACLR.

Conclusions

At 2 years after surgery, KT-1000 testing showed less than 1 mm side-to-side difference and no differences were observed between the groups in the percentage of patients who met or exceeded the MCID. Significantly higher early patient-reported outcome scores were found with SAACLR versus CACLR. The rerupture rate between the groups was not significantly different.

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