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Anterior cruciate ligament repair versus reconstruction: A clinical, MRI and patient-reported outcome comparison

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ABSTRACT

Background: There has been a resurgence in anterior cruciate ligament (ACL) repair for proximal tears using modern surgical techniques and technology. This study aims to compare ACL repair with reconstruction using MRI, clinician-measured and patient-reported outcome measures (PROMs).
Methods: A post-hoc analysis was performed on prospectively collected data from 20 consecutive primary ACL repairs by the senior author. This was compared with an age and sex-matched cohort of 20 ACL reconstructions by the same surgeon using PROMs, return-to-sport (RTS) testing, and MRI signal noise quotient (SNQ).
Results: Repairs demonstrated equivalent post-operative PROMs to reconstructions as measured by International Knee Documentation Committee subjective score (78.5 ± 17.1 vs. 83.7 ± 13.3, $P = 0.333$), Tegner Activity Scale (5.9 ± 1.8 vs. 6.1 ± 2.6, $P = 0.646$) and Lysholm score (89.8 ± 10.0 vs. 89.6 ± 10.4, $P = 0.762$). There was no difference in repairs and reconstructions passing quadriceps strength criteria (50% vs. 53%, $P = 0.097$). A greater proportion of repairs passed hamstrings strength criteria (86% vs. 60%, $P = 0.023$) and hamstrings-to-quadriceps ratio (71% vs. 20%, $P = 0.003$). There were no differences across hop and Y-balance testing. Repairs had earlier RTS assessment (8.2 ± 2.8 months vs. 10.6 ± 1.4 months, $P = 0.020$). On 12-month MRI, repairs demonstrated higher femoral (8.8 ± 5.7 vs. 4.6 ± 2.9, $P = 0.009$) and tibial SNQ (10.0 ± 5.7 vs. 4.3 ± 4.2, $P = 0.001$), with no mid-substance difference (12.3 ± 8.5 vs. 7.6 ± 5.2, $P = 0.074$). There were no graft failures.
Conclusions: When patient selection is optimized for proximal tears, ACL repairs demonstrate equivalent PROMs and better objective outcomes to reconstructions at an earlier timepoint. Repair tissue quality on MRI shows higher signal at tibial and femoral attachments.

1. Introduction

Anterior cruciate ligament (ACL) repair was first reported in the 1890s [1], and up until the mid-1980s it was the most commonly performed surgical treatment for ACL rupture [2]. In the mid-1970s, reports of intraoperative complications, decreased range of motion and poor results in the mid-term including failure and re-rupture started to gain prominence

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[3]. This was likely due to a combination of sub-optimally chosen patient cohorts, an invasive open repair technique with absorbable suturing, and non-functional rehabilitation comprising prolonged cast immobilization [3–6].

Based on a number of randomized prospective controlled trials, reconstruction became the favoured approach [7,8]. However, reconstruction has its own disadvantages - including significant rates of reduced activity level, significant rates of re-rupture and/or contralateral ACL rupture, loss of proprioception [9]; disruption of the physes in children; morbidity of the donor site with autograft, or higher failure rates with allograft; potentially complex revision surgery; and early onset osteoarthritis – and therefore itself may not be appropriate as a one-size-fits-all approach [10].

Interest in repair was reignited with recognition of Sherman et al.'s 1991 paper [11], which demonstrated that proper patient selection produced equivalent results to reconstruction. This was further reinforced recently by DiFelice et al. [12] re-examining historical data focusing on tear location segmentation, showing good results in their cohort of proximal tears. Hence, ACL repair was subsequently re-introduced and updated using modern arthroscopic surgical techniques.

There are multiple potential benefits of repair – theoretically the native ACL is the 'perfect graft', an anatomically perfect fit for the patient with existing neurological and vascular population. Particularly for proximal tears, which involve more vascularised tissue and hence greater healing potential [13], the less-invasive arthroscopic primary repair has a shorter operative time; preserves native tissue and hence proprioception (as measured by static and active joint position sensing, and time-to-detect passive motion sensing) [14]; has no harvest site morbidity, and perhaps a potential faster return to activity as a result. Furthermore, repair avoids the weakening of the knee musculature by allograft, and reconstruction remains an easy option if repair fails [15]. Given these benefits, there has been renewed interest in primary ACL repair. This has been facilitated by the understanding of the significance of tear location in patient selection (proximal tears), coupled with the development of magnetic resonance imaging (MRI) allowing for appropriate patient selection via identification of these tears, the advent of less-invasive arthroscopic technology and solid fixation modes to achieve tension and where needed, augmentation; and early post-operative mobilization and functional rehabilitation [16]. In recent years, newer techniques to augment repairs have been developed including internal bracing (IB) to support the healing repair.

This study aims to compare outcomes between a series of direct ACL repairs with IB augmentation and an age- and sex-matched cohort of ACL reconstructions with IB using subjective patient-reported outcome measures (PROMs), objective clinician-measured outcomes, and MRI outcomes.

2. Methods

2.1. Study design

A retrospective analysis was performed on prospectively collected data. Between February 2017 and September 2020, sequential patients undergoing primary ACL repair with IB were prospectively enrolled to collect data on factors that may affect patient outcomes and ACL re-injury. The study design was approved by the Human Research Ethics Committee of Northern Sydney Local Health District (NSLHD reference: RESP/17/110) and each participant provided informed consent. The inclusion criterion was primary arthroscopic ACL repair with IB. Patients were selected for repair if their MRI showed an ACL that ruptured at its proximal femoral attachment (Sherman classification 1 or 2), and they were skeletally mature. They were consented for repair ± reconstruction and the definitive decision to repair would be made at the time of surgery if the ACL was of sufficient quality to hold two locking sutures, and if it was able to be reduced to its anatomical footprint. Exclusion criteria were ACL bony avulsion including tibial spine avulsion, and surgery more than 1 year from date of injury. Twenty-five patients satisfied these inclusion criteria. Five patients were lost to follow up or missing significant data, leaving a cohort of 20 patients. These were then analysed, and compared with an age- and sex-matched cohort of 20 patients who had a primary ACL reconstruction with IB.

2.2. Surgical technique

ACL reconstruction followed a previously published technique involving hamstring autograft with bicortical suspensory fixation and internal brace [17]. The semitendinosus tendon (ST) was harvested, quadrupled and sized, with additional gracilis tendon harvest if the ST graft diameter was less than 8 mm. An internal brace was added with independent fixation at both femur and tibia.

In the repair group the initial surgical step was an arthroscopic assessment of the ruptured ACL via a high anterolateral and low anteromedial portal. Following careful dissection of the proximal aspect of the remaining ACL tissue, the ACL was assessed for its suitability for repair. Repair proceeded if the residual ACL tissue was of sufficient quality to hold two locking sutures and was reducible to its anatomical femoral footprint.

If suitable for repair, two 13-mm locking sutures (FiberLink) were passed around the proximal third of the ACL stump, perpendicular to each other, using a meniscal Scorpion suture passer, and were retained and parked out of the medial portal (Figure 1). The ACL footprint was then prepared at the site of desired reattachment; a sharp curette was used to expose bone, and a sharp awl or high speed curved arthroscopic drill was used to perform a microfracture over the region of intended healing. To pass the femoral shuttle suture, an outside–in femoral guide (Arthrex Flipcutter) was used to drill a 3.5-mm tunnel to the centre of the footprint, and a suture shuttle (FiberStick) was passed through and retrieved out of the anteromedial

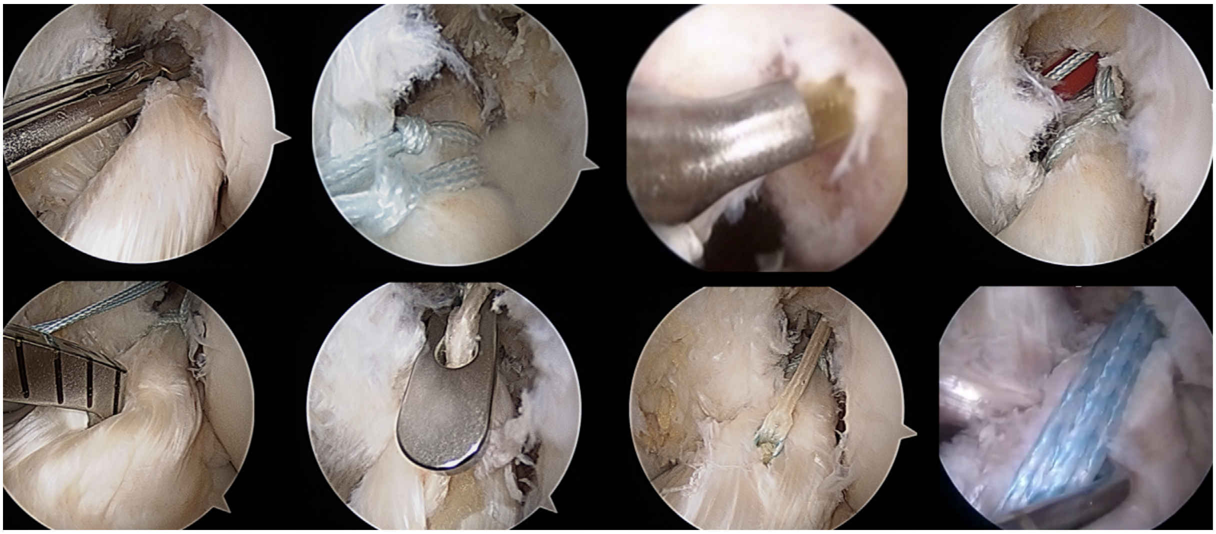

Figure 1. Anterior cruciate ligament (ACL) repair technique. From left to right, top to bottom: (1) ACL stump secured with two locking sutures; (2) ACL footprint prepared and microfracture induced; (3) femoral tunnel prepared; (4) femoral shuttle suture passed; (5) tibial tunnel prepared; (6) tibial shuttle suture passed; (7) internal brace passed.

portal. Similarly on the tibia, an ACL footprint guide (Arthrex) was centred on the ACL tibial footprint, a 3.5-mm drill guide pin was used to create a small tibial tunnel, and a second suture shuttle (FiberStick) was inserted, retrieved, and parked out of the medial portal. This was then used to shuttle the repair sutures out of the tibial tunnel, with care taken to avoid a tissue bridge.

An adjustable loop suspensory fixation device (TightRope RT, Arthrex) was loaded with a FiberTape suture on the button itself, the adjustable loop lengthened, and the construct shuttled up the tibia, across the joint, out of the femur and flipped on to the lateral cortex. The free ends of the repair sutures were then passed over the loop of the TightRope RT and this TightRope loop shortened while the free end of the repair sutures at the tibial end were held, drawing the repair sutures up into the joint, until the RT loop was 5 mm into the femoral tunnel. The tibial ends of the repair sutures were then pulled, putting tension on the proximal ACL tissue and drawing the ACL stump against the prepared femoral footprint. For fixation, the free ends of these repair sutures were fixed to the tibia with a 4.75-mm SwivelLock anchor. The knee was cycled and final tensioning performed via the TightRope RT loop being shortened again, further pulling the free proximal end of the ACL against the femoral footprint. Tension was applied until the ACL stump was firmly opposed to the wall of the lateral femoral condyle as assessed with an arthroscopic probe. The position of the knee at this stage was not important, as excessive tension on the repair was limited by opposition of the ACL stump against the lateral femoral condyle. The final step was to fix the internal brace with the knee in full extension to prevent over-constraint, with fixation of the IB to the tibia with another 4.75 mm SwivelLock.

2.3. Post-operative rehabilitation

Post-operatively, all patients were allowed to begin full weightbearing immediately, and no brace was used. Crutches were used for balance until quadriceps function returned and patients were able to walk without a limp, generally between 1 and 2 weeks post-surgery. Rehabilitation involved closed chain quadriceps, gluteal and core reactivation exercises and followed a standard ACL reconstruction rehabilitation schedule for the first 3 months, then accelerated rehabilitation with the aim of return-to-sports (RTS) by 6 months as opposed to 9 months in the reconstruction group. Progress was monitored with subjective surgeon and objective physiotherapy assessment using a standardized protocol. Decision to RTS was objective-based; patients were assessed for injured and contralateral hamstrings and quadriceps strength at 90° flexion using a hand-held dynamometer, Y-balance test, and single leg hop tests. For strength testing, a cut-off of 40% hamstring to quadriceps (H:Q) ratio was required to pass [18], while a 90% injured to healthy (I:H) ratio was required to pass [19].

With respect to Y-balance, maximal reach was measured separately for healthy and surgical sides in the anterior, posteromedial and posterolateral directions. Hop height testing, hop distance testing and total number of side hops were likewise measured for both limbs. For each of these tests, Limb Symmetry Index (LSI) was calculated as the ratio of the score achieved on the surgical side compared with the healthy side. Separate instances of statistics were run with an LSI threshold of 90% and 80% to pass. In testing for the number of side hops, failed hops were also recorded; a ratio of >25% failed hops was defined as an overall fail in side hop testing.

2.4. Data collection

Demographic data including patient age, body mass index (BMI), injury side, and time from injury to surgery were recorded. PROMs including the International Knee Documentation Committee (IKDC) Subjective Score, Lysholm Knee Score and Tegner Activity Scale were collected pre-operatively and at 6 months, 9 months, 12 months and 24 months post-operatively. Knee laxity was measured using the KT-1000 and GNRB devices at 9-month and 12-month follow up for both cohorts. The values reported are for measurements taken at 134 N for both apparatuses. The latest values for PROMs, KT-1000 and GNRB measurements were used for analysis. MRI was performed at 12 months using a previously published protocol, and used to determine ACL integrity and for quantitative analysis [20].

2.5. MRI signal/ noise quotient

For the reconstruction cohort, a previously reported MRI protocol was used for analysis at 12 months post-surgery [20]. InteleViewer software (Intelerad) was used to visualise the ACL on an oblique T2-weighted sagittal view. Three sites were chosen for signal intensity assessment (proximal or femoral, mid-substance, and distal or tibial). A 20 mm^2 ± 0.5 mm^2 circular region of interest (ROI) was measured at each location. The mid-substance site was chosen to have its centre aligned at the level of the anterior-distal intercondylar notch. The distal site was designated just proximal to the tibial aperture, with its distal edge aligned to the joint surface. The femoral measurement was taken proximally along the ACL, equidistant from distal to mid-substance ROIs. The ACL signal intensity was compared with posterior cruciate ligament (PCL) and background signal intensity via the following equation:

$$\mathrm{SNQ} = \frac{\mathrm{ACL\ Signal} - \mathrm{PCL\ Signal}}{\mathrm{Background\ Signal}}$$

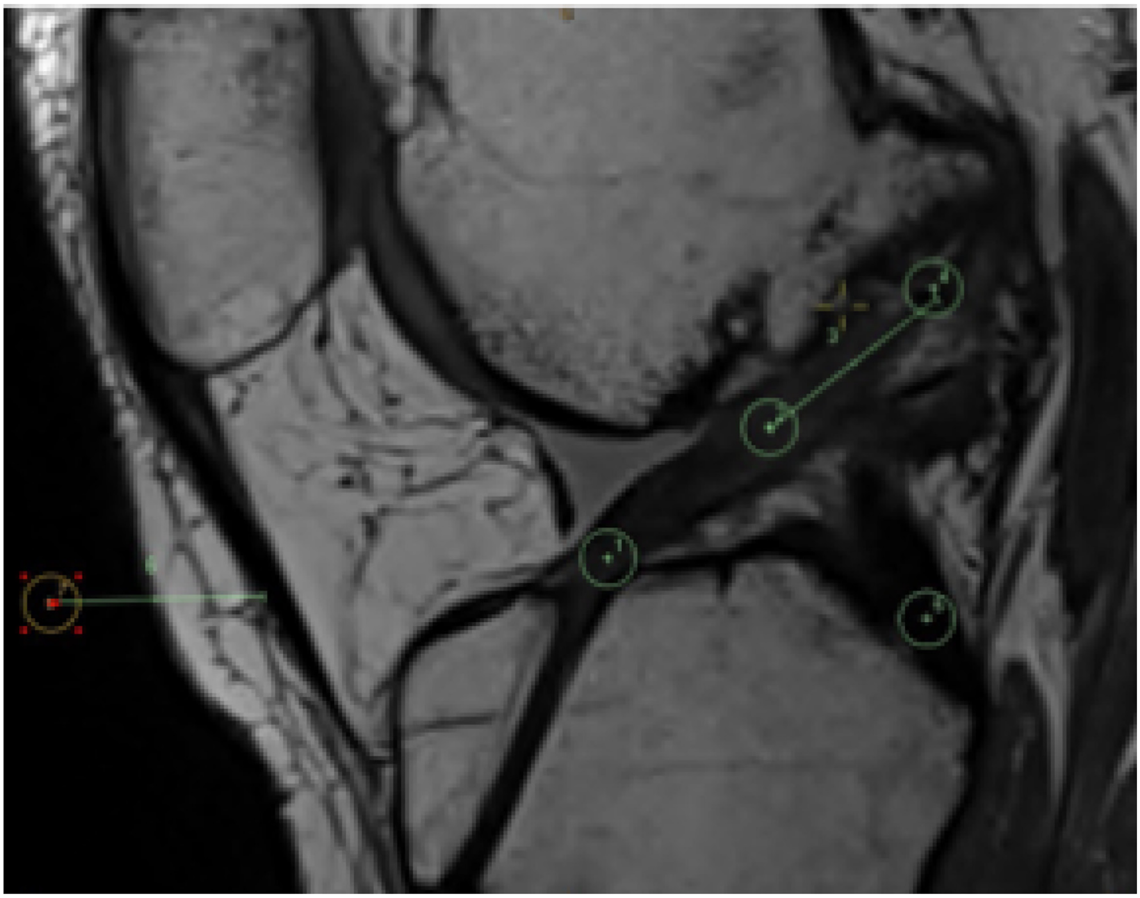

Figure 2. Signal noise quotient analysis on T2 MRI. (1) Distal anterior cruciate ligament (ACL); (2) midsubstance ACL; (3) and (4) proximal ACL, equidistant from (1) to (2); (5) PCL; (6) and (7) background site, 2 cm anterior to patellar tendon.

A separate value was calculated for the proximal, mid-substance and distal sites, as well as an average measurement. The PCL signal was measured at the central slice of the broad distal attachment. Background signal intensity was assessed via an ROI placed 2 cm anterior to the patellar tendon (Figure 2).

This protocol was modified slightly for the repair cohort as repairs would have no ACL tissue in the tibial tunnel; the distal measurement was moved minimally such that the base of the circle abutted the tibia. For intra- and inter-observer reliability, the SNQ values were measured twice by the first author after an interval of 1 week and matched with a further experienced observer (J.D., C.B.). A higher signal intensity and therefore SNQ is assumed to represent poorer quality tissue. Previous research has demonstrated that SNQ reflects the mechanical strength of the graft [21–24]. The intra-rater intraclass correlation coefficient (ICC) was 0.977 for repairs (P = 0.000) and 0.872 (P = 0.000) for reconstructions. Inter-rater ICC was 0.914 for repairs (P = 0.000) and 0.984 for reconstructions (P = 0.001).

2.6. Statistical analysis

IBM SPSS was used for statistical analysis. Prior to comparison between repair and reconstruction cohorts, the Shapiro–Wilk test was used for assessment of normality. To compare between cohorts for parametric variables, the independent samples t-test was used; for non-parametric variables, the Mann–Whitney U-test was used. The chi-square or Fisher's exact test was used to compare categorical data between the groups. The paired t-test and Wilcoxon Signed Ranks test were, respectively, used to compare within repair and reconstruction cohorts pre- and post-operatively for parametric and non-parametric variables. Values provided are mean ± standard deviation unless stated otherwise.

3. Results

3.1. Demographics

Twenty repair and 20 age- and sex-matched reconstruction patients were included in this study. The mean age was 35.7 ± 11.5 years; there were 26 males and 14 females. They were well matched with no significant differences in age at surgery (36.9 ± 12.6 years in repairs compared with 34.4 ± 10.4 years in reconstructions, P = 0.498), pre-operative BMI (28.4 ± 4.2 kg/m^2 in repairs compared with 25.1 ± 3.6 kg/m^2 in reconstructions, P = 0.099), laterality (12 left and eight right in both repairs and reconstructions, P > 0.9999), and time to surgery between repair and reconstruction cohorts (68.4 ± 64.5 days compared with 69.4 ± 47.5 days, P = 0.478). Follow up time was also similar between the cohorts (16.6 ± 10.5 months for repairs compared with 15.3 ± 7.1 months for reconstructions, P = 0.540) (Table 1).

Associated pathologies were recorded. There were 7/20 repairs without any additional injury, and 14/20 reconstructions without any additional injury. There was no significant difference in medial meniscus (P = 0.4506), lateral meniscus (P = 0.1908), medial collateral ligament (P = 0.4872) or cartilaginous injury (P = 1) associated with either cohort (Table 2). Seven repairs and 12 reconstructions required an additional procedure. In particular, there were four meniscal repairs and three meniscectomies among the repair cohort, and 10 meniscal repairs and two meniscectomies amongst reconstructions.

3.2. Patient-reported outcome measures

There was no significant difference between the two cohorts for pre-operative IKDC (Figure 3a), Lysholm (Figure 3b) and Tegner Activity Scale (Figure 3c) (48.2 ± 11.5 compared with 56.1 ± 21.7, P = 0.220; 63.6 ± 18.1 compared with 68.8 ± 20.2, P = 0.491; and 1.8 ± 1.0 compared with 3.2 ± 2.2, P = 0.091, respectively).

There was a significant improvement in pre-operative to post-operative scores in both groups for all PROMS. IKDC subjectively improved for both repair (48.2 ± 11.5–81.4 ± 14.6, P = 0.003) and reconstruction cohorts (56.8 ± 22.3–84.6 ± 13.9, P = 0.000). Similarly, Lysholm scores increased significantly in both repair (63.6 ± 18.1–89.8 ± 10.0, P = 0.001) and reconstruction cohorts (68.8 ± 20.2–89.6 ± 10.4, P = 0.001). Tegner Activity Scale increased from pre-operatively to post-operatively in both cohorts (1.8 ± 1.0–5.9 ± 1.8, P = 0.003 in repairs and 3.2 ± 2.2–6.1 ± 2.6, P = 0.009 in reconstructions).

Table 1
Cohort demographics.

Variable	Repair	Reconstruction	P
Age (years)	36.9 ± 12.6	34.4 ± 10.4	0.498
Pre-operative BMI (kg/m^2)	28.4 ± 4.2	25.1 ± 3.6	0.099
Injury side (L:R)	12:8	12:8	>0.999
Time to surgery (days)	68.4 ± 64.5	69.4 ± 47.5	0.478
Follow up time (months)	16.6 ± 10.5	15.3 ± 7.1	0.540

BMI, body mass index.

Table 2
Additional injuries.

Pathology	Repair (*n*)	Reconstructions (*n*)	*P*
Medial meniscus	3	4	0.4506
Lateral meniscus	5	10	0.1908
Medial collateral ligament	2	0	0.4872
Cartilaginous injury	3	3	1

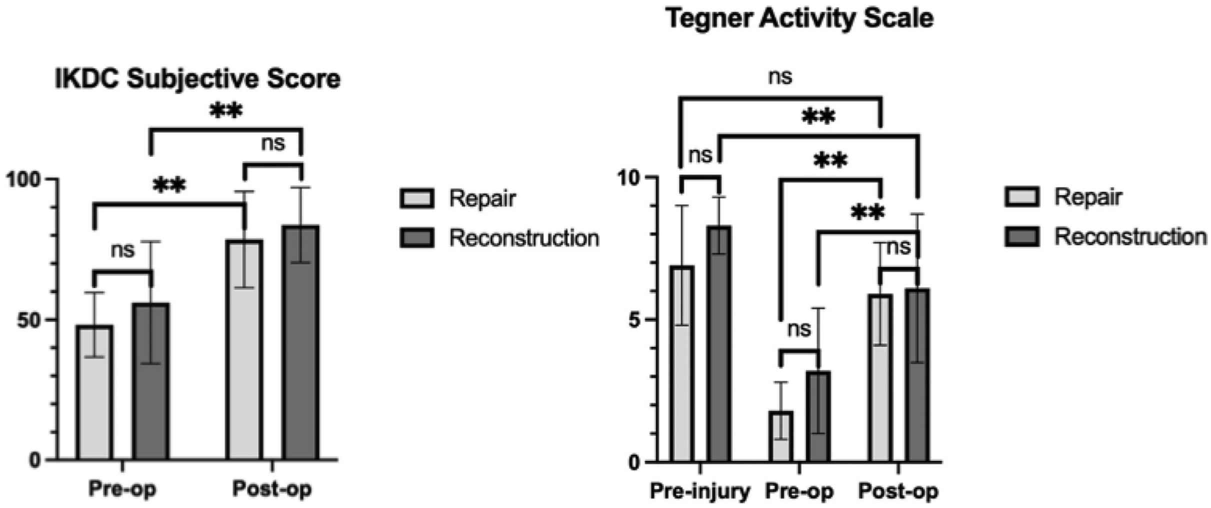

Figure 3. (a) Pre-operative and post-operative International Knee Documentation Committee (IKDC). *P < 0.05; **P < 0.01; ***P < 0.001. (b) Pre-operative and post-operative Lysholm Knee Score. (c) Pre-injury, pre-operative and post-operative Tegner activity scale.

There were no differences between the groups with regard to the amount of improvement from pre- to post-operative for IKDC subjective (32.9 ± 13.8 for repairs, 27.8 ± 22.8 for reconstructions, P = 0.716) or Lysholm (25.8 ± 15.7 for repairs, 19.1 ± 19.7 for reconstructios, P = 0.241), or Tegner Activity Scale (3.7 ± 1.6 for repairs and 3 ± 3.4 for reconstructions, P = 0.610).

When comparing post-operatively, there were no differences between the groups in IKDC, Lysholm and Tegner Activity Scale, at 81.4 ± 14.6 vs. 83.4 ± 13.6 (P = 0.674), 89.8 ± 10.0 vs. 89.6 ± 10.4 (P = 0.762) and 5.9 ± 1.8 vs. 6.1 ± 2.6 (P = 0.646) for repairs and reconstructions, respectively.

Pre-injury Tegner Activity Scale was available for seven repair and 15 reconstruction patients. Pre-injury Tegner Activity Scale was not significantly different between the groups, at 6.9 ± 2.1 for repairs and 8.3 ± 1.0 for reconstructions (P = 0.142). Post-operative Tegner Activity Scale was not significantly different from pre-injury levels for repair (6.9 ± 2.1–5.9 ± 1.8, P = 0.593). There was a significant decrease in pre-injury to post-operative Tegner Activity Scale for reconstructions, at 8. 3 ± 1.0–6.1 ± 2.6 (P = 0.016) (Table 3).

Table 3
Patient-reported outcome measures.

Variable	Repair (mean ± SD (*n*))	Reconstruction (mean ± SD (*n*))	*P*
Pre-operative IKDC	48.2 ± 11.5 (11)	56.1 ± 21.7 (17)	0.220
Post-operative IKDC	78.5 ± 17.1 (17)	83.7 ± 13.3 (18)	0.333
ΔIKDC	32.9 ± 13.8 (11)	27.8 ± 22.8 (17)	0.716
Pre-operative Lysholm	63.6 ± 18.1 (11)	68.8 ± 20.2 (17)	0.491
Post-operative Lysholm	89.8 ± 10.0 (15)	89.6 ± 10.4 (18)	0.762
ΔLysholm	25.8 ± 15.7 (11)	19.1 ± 19.7 (17)	0.241
Pre-injury Tegner Activity Scale	6.9 ± 2.1 (7)	8.3 ± 1.0 (15)	0.142
Pre-operative Tegner Activity Scale	1.8 ± 1.0 (11)	3.2 ± 2.2 (17)	0.091
Post-operative Tegner Activity Scale	5.9 ± 1.8 (16)	6.1 ± 2.6 (18)	0.646
ΔTegner Activity Scale (pre-operative to post-operative)	3.7 ± 1.6 (11)	3 ± 3.4 (17)	0.610
ΔTegner Activity Scale (pre-injury to post-operative)	−0.5 ± 1.97 (6)	−1.73 ± 2.31 (15)	0.016

IKDC, International Knee Documentation Committee; SD, standard deviation.

3.3. Clinician-measured outcomes

The repair cohort possessed a shorter time to final RTS assessment than reconstruction (mean 8.2 ± 2.8 months vs. mean 10.6 ± 1.4 months for reconstruction, $P = 0.020$).

Clinician-measured outcomes are shown in Table 4. Regarding quadriceps deficits, 4/8 patients passed among repairs and 8/15 passed among reconstructions ($P = 0.097$). There was a significant difference in the proportion of repair and reconstruction patients who passed hamstring deficits criteria; 6/7 repair patients passed, while only 9/15 reconstructions passed ($P = 0.023$). There were similarly significant differences noted in assessments of hamstrings: quadriceps ratio, with 5/7 repairs passed, while 3/15 reconstructions passed ($P = 0.003$).

There were no significant differences in the number of repairs or reconstructions passing anterior ($P > 0.999$), posteromedial ($P = 0.531$) or posterolateral ($P > 0.999$) Y-balance tests.

There was no significant difference in the proportion of repair and reconstruction patients passing hop distance testing when using a 90% LSI threshold ($P = 0.659$) or 80% LSI threshold (0.618). There were also no significant differences in repairs and reconstructions passing hop height testing for 90% LSI ($P = 0.693$) or 80% LSI ($P = 0.325$), and no differences in total number of side hops at 90% ($P > 0.999$) or 80% LSI ($P = 0.325$). Both groups had a similar proportion of patients passing the failed side hop threshold ($P = 0.381$).

There was no difference in objective stability between the groups as measured via side-side knee laxity with KT-1000 post-operatively (1.8 ± 1.4 mm vs. 1.8 ± 1.3 mm, $P = 0.943$). There were also no post-operative differences in GNRB-measured side-side difference in knee laxity (1.6 ± 1.8 mm in repairs and 1.3 ± 2.0 mm in reconstructions, $P = 0.714$).

3.4. Imaging outcomes

On 12-month MRI there were no re-ruptures among either cohort. Analysis of SNQ measurements (Figure 2 from above) showed repairs possessed higher values at both femoral (8.8 ± 5.7 compared with 4.6 ± 2.9, $P = 0.009$) and tibial sites (10.0 ± 5.7 compared with 4.3 ± 4.2, $P = 0.001$). Mid-substance measurements were not significantly different between the groups (12.3 ± 8.5 in repairs vs. 7.6 ± 5.2 in reconstructions, $P = 0.074$). Repairs also demonstrated higher values on average (10.4 ± 6.3 compared with 5.5 ± 3.5, $P = 0.003$) (Table 5).

Table 4
Clinician-measured outcomes.

Variable	Repair	Reconstruction	*P*
Strength testing			
Quadriceps deficit criteria (pass:fail)	4:4	8:7	0.097
Hamstrings deficit criteria (pass:fail)	6:1	9:6	0.023
Hamstrings: quadriceps ratio (pass:fail)	5:2	3:12	0.003
Y-balance testing			
Y-balance anterior reach (pass:fail)	7:1	10:3	>0.999
Y-balance postero-medial reach (pass:fail)	6:2	12:1	0.531
Y-balance postero-lateral reach (pass:fail)	7:1	10:3	>0.999
Hop testing			
Hop distance (90% LSI threshold)	5:3	6:7	0.659
Hop distance (80% LSI threshold)	6:2	11:2	0.618
Hop height (90% LSI threshold)	4:4	5:8	0.693
Hop height (80% LSI threshold)	5:3	11:2	0.325
Side hops (90% LSI threshold)	4:4	6:7	>0.999
Side hops (80% LSI threshold)	5:3	11:2	0.325
Failed hop (25% threshold)	7:1	13:0	0.381
Laxity testing			
Post-operative KT-1000 side–side difference (mm)	1.8 ± 1.4	1.8 ± 1.3	0.943
Post-operative GNRB side–side difference (mm)	1.6 ± 1.8	1.3 ± 2.0	0.714

Limb Symmetry Index (LSI) was calculated as the ratio of the score achieved on the surgical side compared with the healthy side. Separate instances of statistics were run with an LSI threshold of 90% and 80% to pass. Knee laxity was measured using the KT-1000 and GNRB devices at 134 N for both apparatuses.

Table 5
Imaging outcomes.

Variable	Repair (mean ± SD ($n = 20$))	Reconstruction (mean ± SD ($n = 20$))	*P*
Average SNQ	10.4 ± 6.3	5.5 ± 3.5	0.003
Femoral SNQ	8.8 ± 5.7	4.6 ± 2.9	0.009
Mid-substance SNQ	12.3 ± 8.5	7.6 ± 5.2	0.074
Tibial SNQ	10.0 ± 5.7	4.3 ± 4.2	0.001

SD, standard deviation; SNQ, signal noise quotient.

4. Discussion

This study compared the patient-reported, clinician-measured and imaging outcomes of primary ACL repair as compared with reconstruction in a matched cohort. There were no significant differences in PROMs of IKDC, Lysholm or Tegner Activity Scale or side–side laxity as measured by KT-1000 and GNRB. RTS outcomes were superior in the repair cohort, primarily with regard to hamstring strength and hamstrings: quadriceps ratios with all other measures equal. It should be noted that the results in repair groups were functionally equivalent, but achieved at an earlier timepoint post-surgery. MRI assessment showed repairs had higher signal intensity at the tibial and femoral sites, but similar mid-substance values.

To our knowledge this is the first direct comparison assessing PROMs in ACL repair and reconstruction with internal bracing, but our findings were similar to pre-existing literature on other techniques including suture anchoring [25]; dynamic intraligamentary stabilisation [26–28] and bridge-enhanced repair (BEAR) [29].

Repairs demonstrated equivalent results to reconstructions for post-operative side-side knee laxity measurements as measured by the KT-1000 and GNRB. These KT-1000 results were similar to those of Achtnich et al. [25] (1.95 ± 1.7 mm in repairs vs. 1.15 ± 0.67 mm in reconstructions, $P = 0.269$) and Murray et al. [29] (1.61 ± 3.16 mm in BEAR vs. 1.77 ± 2.79 mm in reconstruction, $P = 0.82$). Within the literature, this is the only study to have compared the outcomes of the two surgeries using GNRB.

Despite shorter time to assessment, at mean 8.2 months compared with 10.6 months, our repair cohort demonstrated superior results to reconstructions on RTS testing, in particular for hamstrings deficits criteria (6/7 passes in repairs and 9/15 passes in reconstructions, $P = 0.023$) and hamstrings: quadriceps ratio criteria (5/7 passes in repairs and 3/15 passes in reconstructions, $P = 0.003$). This is likely due to the absence of hamstring harvesting in repairs, but is relevant to those aiming for earliest return to activity. Y-balance and hop testing were statistically equivocal between the two groups across all modalities assessed, though again the earlier time point for the repairs should be noted. Ortmaier et al. [30] focused on RTS in internal brace augmented repairs compared with semitendinosus or quadriceps tendon autograft. There was no significant difference in overall return-to-sports rate or subjective ratings between the groups. However, the authors defined return to sports as patients returning to the same level of sporting activity – even if the sport itself changed from a knee-demanding sport discipline to another. Further, this study's design, involving entirely patient-reported outcomes via retrospective questionnaire, serves as a limitation and area of potential recall bias when compared with our objective and validated measurements.

Our study showed repairs demonstrated significantly higher signal intensity on MRI at tibial and femoral sites, and subsequently on average. This is the first comparative study using MRI in ACL repair. In reconstruction literature, higher graft signal is thought to represent incomplete or ongoing healing, and some literature including from our group has shown a correlation with failure and re-rupture [17]. While the femoral site of repair patients is comprised of healing native tissue and would logically be of higher intensity compared with graft tissue, the explanation for tibial site intensity is unknown. We hypothesise that these findings may be due to incomplete healing of trauma associated with passage of the internal brace, or from the primary injury which may distort without fully disrupting all regions of the remaining ACL tissue, including the 'intact' tibial end of the ACL. These results should be interpreted with the caveat that SNQ may not be measuring the same outcome in repairs and reconstructions – without corresponding literature on native ACL tissue it is not possible to definitively confirm whether it is also a measure of repair healing and tissue quality. To our knowledge, MRI signal intensity has not previously been compared between ACL repair and reconstruction, and within the existing literature, only Achtnich et al. [25] evaluated radiological findings via sagittal MRI; all MRIs in this study's reconstruction group demonstrated an intact ACL, while three repairs had re-ruptured. However, no further statistical analysis was conducted.

Limitations of our study are those associated with retrospective assessment and PROMs; relatively small numbers which may be underpowered to demonstrate clinically significant results; and early follow up time, wherein 12 months is likely insufficient to report final overall re-rupture rates and MRI SNQ in either group. Moreover, our cohorts included patients with additional injuries such as meniscal tears, which may be a confounding factor.

5. Conclusion

ACL repair is a resurging modality for surgical management of proximal ACL tears in appropriate patients. Patient selection seems critical. In these patients, repair yields similar PROMs and superior outcomes on RTS assessment at an earlier timepoint, with equivalent side–side knee laxity. Repairs possessed higher signal intensity at femoral and tibial attachment sites compared with reconstructions at 12 months, with further research required to define the clinical significance of this finding.

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7. Ethics committee letter

The study design was approved by Human Research Ethics Committee of Northern Sydney Local Health District (NSLHD reference: RESP/17/110).

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: 'J.K.H.D. and G.T.M. have no potential conflicts of interest to declare. C.B. has carried out paid work for Arthrex and for Depuy/Synthes. B.A.F. has received funding from and has carried out paid work for Arthrex'.

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