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Original Research

Deficits in muscle strength are not seen following recovery from augmented primary repair of anterior cruciate ligament tears

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ABSTRACT

Objectives: Anterior cruciate ligament (ACL) repair for proximal tears, where the ligament is re-attached and augmented with suture tape, can negate the need for graft harvest, thereby maintaining native anatomy. Autograft harvest has been associated with persistent deficits in lower limb muscle strength after recovery from ACL reconstruction. The aim of this study is to compare lower limb muscle strength following ACL repair and reconstruction.

Methods: Nineteen ACL repair patients augmented with suture tape and nineteen ipsilateral semitendinosus-gracilis autograft ACL reconstruction patients (both mean 4 years postoperatively) were recruited, along with twenty healthy volunteers. Patient-reported outcome measures (PROMs) were obtained using the Knee Injury and Osteoarthritis Outcome Score (KOOS), Lysholm, and Tegner scores. Maximal isometric quadriceps and hamstring strength at 90° knee flexion were measured using a fixed Myometer after a warm-up and three maximal-effort contractions.

Results: Mean hamstring strength of the reconstructed legs was lower than that of healthy volunteers by 0.29 Nm/kg. The hamstring strength ratio of the operated side to the uninjured side was greater in the repair (95% ± 13) than in the reconstruction (81% ± 18) group. There were no statistically significant differences between sides for quadriceps peak torque or for hamstrings in the volunteer or repair group. PROMs scores for the reconstruction group were significantly lower than volunteers across all domains and lower than repair for KOOS activities of daily living and Lysholm scores.

Conclusion: Hamstring weakness seen following ACL reconstruction is not evident following ACL repair with suture tape augmentation. Strength asymmetry could contribute to re-injury risk and influence functional performance, while altered loads affect knee biomechanics and may lead to osteoarthritis progression. The absence of these deficits in the repair group demonstrates a potential benefit of this technique when used in appropriate patients.

Level of evidence: II.

What are the new findings?

- Primary anterior cruciate ligament repair with suture augmentation has satisfactory patient-reported outcomes and laxity measurements.
- Hamstring strength deficits, which are present following recovery from anterior cruciate ligament reconstruction, are not seen following primary repair, with potential for improved functional outcomes.

Introduction

Anterior cruciate ligament (ACL) reconstruction is the gold standard surgical procedure for addressing an ACL rupture, usually requiring an autologous tendon graft to replace the native ACL. Reconstruction using an autologous bone-patellar tendon-bone or hamstring tendon graft has been associated with donor site morbidity in the form of knee extension or flexion weakness, respectively [1–3]. Ardern, Webster et al. [4] demonstrated hamstring weakness of up to 27% compared with the uninjured limb despite the successful completion of rehabilitation. These

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asymmetric strength reductions can persist long after recovery, with potential implications for neuromuscular control and function [3,5,6].

The realisation of the limitations of ACL reconstruction has led to renewed interest in ACL repair surgery [7]. Primary repair techniques, where the native ACL is preserved and augmented with suture tape, attempt to restore normal knee anatomy while obviating the need for graft harvest. Studies into this technique have shown promising results for healing potential [8,9]. Although early clinical outcome studies have shown results similar to those of ACL reconstruction, little is known of the functional outcomes [10–13].

The aim of this study was to compare lower limb strength (quadriceps and hamstring) following recovery from ACL repair and reconstruction surgery. The authors hypothesised that there would be no statistical difference in quadriceps or hamstring strength between either the repair versus uninjured limb, the repair limb versus the reconstruction limb, or the repair and reconstruction versus dominant limb of healthy volunteer controls.

Methods

Participant recruitment

Following appropriate ethical approvals (UEC19/24), 19 patients who had undergone primary ACL repair augmented with suture tape were recruited prospectively. The surgical technique involved arthroscopic re-attachment of the torn ACL to its origin on the medial wall of the lateral femoral condyle and augmentation with an internal brace (Arthrex, Naples FL, USA) [8].

Additionally, 20 healthy volunteers and 19 patients who had ACL reconstruction using ipsilateral hamstring autografts were also recruited. The patients were selected at random from the operative register using a random number generator and invited to participate, while the healthy volunteers were recruited through online advertising within our institution. There was no financial incentive to take part; however, travel costs were reimbursed. The surgical technique for the reconstruction involved a four-strand semitendinosus-gracilis graft, fixed on the femoral side with a loop button device in the anteromedial bundle position and on the tibial side with an interference screw.

Inclusion criteria for all groups were males and females, aged 16–50 years, with a minimum Tegner score of 3 at the time of enrolment and without any other concomitant musculoskeletal pathology. For the patient groups, participants were eligible if they had a proximal ACL tear (Modified Sherman grade 1 or 2) [14] treated operatively between one and ten years prior to testing. Patients with multiligament injuries, associated injuries requiring concomitant operative intervention, or those with a history of contralateral knee injury or ipsilateral re-injury/revision were excluded. All measures were taken against all participants after they indicated their willingness to participate by signing informed consent.

Subjective and objective outcome assessment

Patient-reported outcome measures (PROMs) were obtained using the Knee Injury and Osteoarthritis Outcome Score (KOOS), Lysholm and Tegner activity scales. Knee stability was measured using the Rolimeter (Aircast Europa, Neubeuern, Germany) for Lachman (30° knee flexion) and anterior drawer tests (90° knee flexion). Pivot shift testing was performed by a trained clinician, independent of the treating clinician, and graded as per the International Knee Documentation Committee (IKDC) classification.

Strength testing

Following a warm-up that consisted of 2 min of light jogging followed by ten body-weight squats, maximal isometric quadriceps and hamstring strength were measured using a fixed myometer (MIE, Medical Research Ltd., UK). To do so, volunteers sat with their hips and knees flexed to 90° and were asked to attempt to flex and extend their knees as strongly as they could. A strap was attached to the leg, approximately 5–10 cm proximal to the medial malleolus (Fig. 1). The actual distance from the lateral femoral epicondyle to the strap position on the leg was measured using a tape measure and recorded to determine the moment arm. Participants performed three maximal isometric contractions, each held for 3 s for each leg, with a minimum 10 s rest in between each repetition. Torque was calculated by multiplying the maximum force achieved by the moment arm and normalising with respect to body mass.

Statistical analysis

The recruited sample size was calculated based on an assumed clinically significant limb symmetry index (LSI) difference between the two treatment groups of 10%. This was guided using data from a previous study analysing strength after ACL reconstruction [15]. For a power of 0.8, at an alpha level of 0.05, 16 participants were estimated to be required in each group. In order to allow for potential dropouts, we aimed to recruit 20 participants in each group; however, there were no withdrawals.

LSI was calculated by comparing the operated and uninjured side. Using the uninjured side as a reference for assessing deficits on the operated side is a commonly used and validated technique [16]. For comparisons with the healthy volunteer group, the dominant leg was used in all cases, as no statistically significant difference was demonstrated between dominant and non-dominant in this group. Statistics were calculated using SPSS (Chicago, USA), with data assessed for normality using the Shapiro–Wilk test. For comparison between the three groups, a one-way ANOVA was used for parametric data with a post-hoc Tukey test. In cases of non-parametric distribution, the Kruskal–Wallis test was used, along with post-hoc Mann–Whitney tests. Paired t-tests were used between legs of the same subject, and statistical significance was set at $p = 0.05$.

Results

In total, 58 participants were recruited: 20 healthy volunteers, 19 ACL repair patients, and 19 ACL reconstruction patients. There were no statistically significant differences in patient factors between groups; mean age 29, 64% male, pre-injury Tegner scale 7 (range 4–10) (Table 1). Testing was performed at a mean of 4 years (±1.8) post-operatively for the repair group and mean 4 years (±1.5) post-operatively for the reconstruction group.

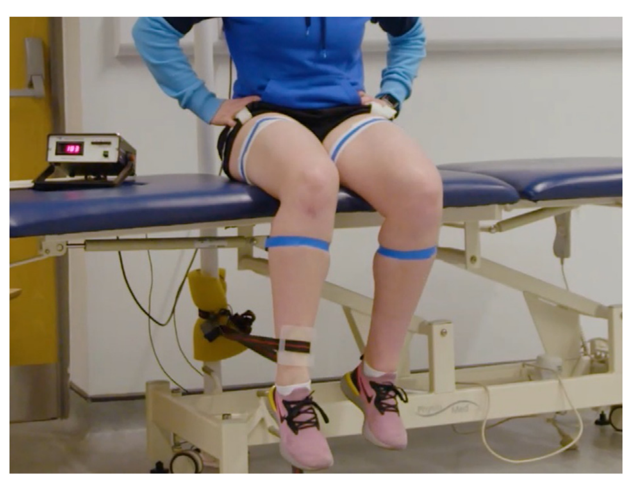

Fig. 1. Photograph demonstrating setup for isometric quadriceps strength test using fixed myometer

Table 1
Demographic data and activity level by group (mean ± SD).

	Volunteer	Repair	Reconstruction	p-value
n	20 (13 male)	19 (11 male)	19 (13 male)	0.7
Age (years)	29.8 (±4)	29.8 (±11)	28.0 (±7)	0.8
Height (m)	1.75 (±0.11)	1.72 (±0.09)	1.72 (±0.10)	0.4
Weight (kg)	76 (±16)	77 (±16)	81 (±14)	0.6
Time post-op (years)	N/A	4.3 (±1.8)	4.2 (±1.5)	0.8
Pre-injury Tegner activity score	7 (±2)	7 (±2)	7 (±2)	0.8

Lower postoperative PROMs were observed for the reconstruction group compared to repair and healthy volunteers (Table 2). Post hoc tests indicated that PROMs scores for the reconstruction group were significantly lower than those of healthy volunteers across all domains and significantly lower than those of repair for KOOS activities of daily living (ADL) and also for the Lysholm score ($p < 0.05$) (Table 2). In contrast, the repair group scores were not different from those of healthy volunteers for the KOOS pain, symptoms, ADL, or Lysholm domains. There was no statistically significant difference between groups for the current Tegner score; however, there was a one-point decrease in the current score compared to pre-injury for both treatment groups ($p < 0.05$).

There were no statistically significant differences between sides for isometric quadriceps or hamstring peak torques in the volunteer or repair group (Table 3). There was, however, a significant difference for the reconstruction group with hamstring weakness of the operated side ($p < 0.001$) (Fig. 2). The LSI was significantly greater for mean hamstring peak torque in the repair group (95%) compared to the reconstruction group (81%; $p < 0.001$), although there was no difference as it pertains to quadriceps strength (101% vs. 105%, $p = 0.54$) (Fig. 2).

Group membership affected the hamstring strength of the injured leg ($p = 0.002$), and subsequent post hoc tests revealed that the mean hamstring strength of the reconstructed legs was significantly lower than that of the healthy volunteers by 0.29 Nm/kg ($p = 0.002$) (Fig. 2). There were no statistically significant differences between the healthy and repair groups ($p = 0.17$) for hamstring strength, and quadriceps strength was unaffected by group membership ($p = 0.72$).

Positive correlations existed between hamstring strength LSI and PROMs across all domains ($r_s = 0.37$ to 0.52, all $p < 0.01$).

Instrumented laxity testing using the Rolimeter for the Lachman test showed no difference across the three groups, with a mean anterior laxity of 4 mm for the operated side (Table 3). The mean side-to-side difference for Lachman was 0.3 mm for volunteers, 0.2 mm for repair, and 0.4 mm for the reconstruction group. There was one patient in each group with a side-to-side difference of >3 mm, both of which had a positive pivot shift test.

Laxity testing at 90° showed greater mean displacement for reconstructions (4.5 mm volunteer, 4.6 mm repair, 5.7 mm reconstruction, $p = 0.04$). The mean side-to-side difference was 0.5 mm for volunteers, 0.3 mm for repair, and 0.8 mm for reconstruction group ($p = 0.03$).

Table 2
Average PROMs scores for each group.

	Volunteer	Repair	Reconstruction	p-value
KOOS pain[a]	100 (3)	97 (8)	94 (14)	0.018
KOOS symptoms[a]	96 (10)	93 (18)	79 (18)	0.008
KOOS ADL[a]	100 (0)	100 (0)	99 (6)	<0.001
KOOS sport[a]	100 (0)	90 (10)	85 (20)	<0.001
KOOS QOL[a]	100 (5)	81 (38)	75 (25)	<0.001
Lysholm[a]	100 (5)	95 (15)	88 (7)	<0.001
Current Tegner activity score [b]	7.0 (±1.5)	6.2 (±1.9)	6.1 (±2.1)	0.2

[a] Median (interquartile range).
[b] Mean (±SD). KOOS, knee injury and osteoarthritis outcome score; ADL, activities of daily living; QOL, quality of life.

Discussion

The realisation of the limitations associated with ACL reconstruction has prompted renewed interest in other techniques that could improve outcomes after ACL rupture. Modern arthroscopic surgical instrumentation has made repair of ACL tissue easier, and advancements in functional tissue engineering and regenerative medicine have resulted in a revival of ACL repair [7,17]. Theoretically, this technique could restore normal patient anatomy without causing donor site morbidity that can be associated with reconstructions [18].

There are few studies investigating the functional outcomes following this technique of augmented ACL repair surgery. On the other hand, there has been a lot of focus on recovery following ACL reconstruction. It is generally accepted that strength deficits are present in the early postoperative period following ACL reconstruction; however, controversy exists over the extent and timing of recovery [18–21].

The results of this study confirm those of other studies that deficits in hamstring strength persist following ACL reconstruction [3,4,21–26]. Ardern, Webster et al. [4] found, in a similar study focusing on ACL reconstruction with hamstring autograft, that at 90° of knee flexion, there was a side-to-side hamstring strength deficit of 24% in patients at around 3 years post-operatively. Our results show a deficit of 19% for the reconstruction group after 4.2 years, which supports that finding.

This is the first study to investigate this outcome in patients following augmented ACL repair. We found that quadriceps and hamstring strength are not adversely affected at an average of 4 years post-operatively from ACL repair when compared to the uninjured knee and a group of healthy volunteers. This contrasts with the findings for the ACL reconstruction group, which has persistent weakness compared to healthy subjects and an asymmetry of lower limb strength.

Quadriceps and hamstring contractions have been shown to provide the majority of support for the knee adduction moment during walking [27] and are also vital for frontal plane stabilisation during sporting tasks [6]. Hamstrings act to prevent anterior tibial translation and rotation, functions that are synergistic with the ACL and therefore may share stress with the ACL [28]. Hamstring weakness; therefore, could contribute to graft failure following ACL reconstruction [29]. Indeed, failing to meet strength symmetry criteria prior to returning to sport, in particular a reduced hamstring to quadriceps ratio, results in a four-fold increase in re-rupture risk [29]. In this study, the hamstring to quadriceps strength ratio was 59% for reconstructed knees, 77% for repaired knees, and 81% for the dominant knee of healthy volunteers. The uninjured knees of the patient groups had ratios of 75% and 81% for reconstruction and repair, respectively. The result of this is a marked muscular imbalance in the reconstructed knees. Asymmetries in muscle strength, flexibility, and coordination have been shown to be important predictors of increased injury risk [30,31]. Knapik, Bauman et al. [32] demonstrated that side-to-side equivalence in strength is important for the prevention of injuries, and when imbalances are present, athletes are more commonly injured. Quadriceps strength symmetry has been reported as an important factor to consider for recovery following ACL reconstruction, even with a hamstring autograft [15,33]. Extensor strength deficits are well recognised following patellar or quadriceps tendon autograft harvest [15]. These studies have shown deficits that persist long into the rehabilitation process, with significant implications for returning to sport. It was therefore reassuring to see that quadriceps strength was symmetrical in both the repair and reconstruction cohorts at four years postoperatively in this study.

The hamstring strength deficit seen for the reconstruction group exceeds the 10% deficit that the authors estimated to be of clinical significance. Indeed, the correlation of hamstring LSI with PROMs scores in this study suggests that asymmetry in hamstring strength may influence functional performance, potentially explaining the lower PROM scores in the reconstruction group, when compared to the

Table 3
Peak torque and LSI results for hamstring and quadriceps strength and instrumented laxity measurements for each group (mean ± SD).

Strength		Volunteer	Repair	Reconstruction	p-value
Hamstring	Peak torque operated (Nm/kg)	n/a	0.81 (±0.18)	0.66 (±0.28)	0.002
	Peak torque uninjured (Nm/kg)	0.95 (±0.27)	0.87 (±0.22)	0.81 (±0.26)	0.35
	LSI (operated:uninjured %)	n/a	95 (±13)	81 (±18)	<0.001
Quadriceps	Peak torque operated (Nm/kg)	n/a	1.38 (±0.43)	1.40 (±0.54)	0.72
	Peak torque uninjured (Nm/kg)	1.50 (±0.55)	1.40 (±0.39)	1.36 (±0.55)	0.39
	LSI (operated:uninjured %)	n/a	101 (±22)	105 (±18)	0.54
Instrumented laxity	**Knee flexion (°)**	**Volunteer**	**Repair**	**Reconstruction**	**p-value**
Amount of displacement	30	4.2 (±1.1)	3.9 (±1.0)	4.5 (±1.5)	0.4
operated side (mm)	90	4.5 (±1.5)	4.6 (±1.1)	5.7 (±1.7)	0.04
Side-to-side difference	30	0.3 (±1.1)	0.2 (±1.7)	0.4 (±1.1)	0.2
(operated-uninjured) (mm)	90	0.5 (±1.6)	0.3 (±1.6)	0.8 (±1.6)	0.03

LSI, limb symmetry index.

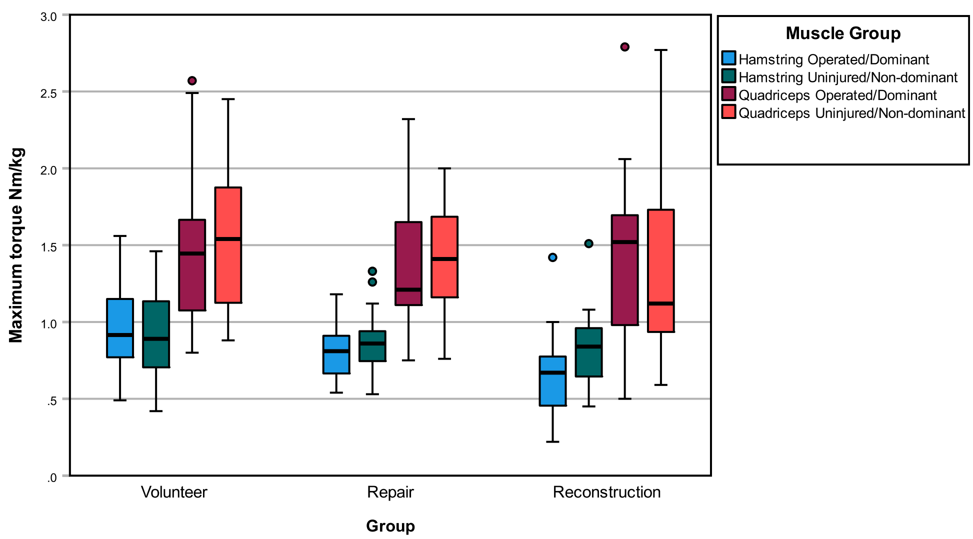

Fig. 2. Graph showing mean peak torque for quadriceps and hamstrings in each group; operated/uninjured leg for patient groups; dominant/non-dominant leg for the volunteer group.

repair group and healthy volunteers. Other studies comparing ACL reconstruction patients with healthy volunteers have previously made this link [34–36]. Indeed, the link between strength deficits and PROMs and readiness for return to sport has been described previously [23,37,38]. Longer term, asymmetry may cause altered loads across the knee, contributing to the development of osteoarthritis [35]. The absence of this deficit in the repair group is an encouraging finding for the outcome of these patients.

The results show augmented ACL repair stability, which is matched to the contralateral knee when assessed by quantifying antero-posterior laxity. Both ACL repair and reconstruction restored laxity to values close to the contralateral knee, healthy volunteer knees, and those previously described in the literature [39,40]. The current study utilises the Rolimeter to quantify laxity, which has been shown to be as reliable as the more commonly used KT-1000® [41,42]. For laxity testing at 90° knee flexion, there was more laxity and a greater side-to-side difference found in the reconstruction group, suggesting that anteromedial graft positioning restores stability better at 30° than 90°, whereas for ACL repair, the restoration of an anatomic ACL is stable in both positions. Previous studies investigating the effect of femoral tunnel placement on laxity measures in ACL reconstruction have not demonstrated a difference between Lachman and anterior drawer tests [43,44].

The findings of this study provide evidence, which has so far been lacking, to demonstrate satisfactory recovery following ACL repair. The PROMs results showed no significant difference in average scores for the repair group compared to healthy volunteers. In contrast, the average scores for the reconstruction group had significant differences that exceeded the minimal clinically important difference. It should be noted; however, that the patients selected for this study were those who were not known to have suffered a re-injury or failure of repair. Current evidence suggests that the failure rate following ACL repair is approximately 8–17% at 2–5 years [11–13], which is higher than those reported in some data registries for ACL reconstruction [45,46]. Failure rates are higher in younger and more active patients following ACL repair; however, the same is true for ACL reconstruction [12]. Careful patient selection for ACL repair is therefore of utmost importance. Only those with proximal tears are suitable for this type of primary repair, and the procedure should be performed soon after injury, ideally within six weeks. Patients should be counselled regarding the potential benefits of repair, such as those described in this study, as well as the potential for a higher risk of early failure. There is, however, no significant difference demonstrated between rates of secondary surgery after ACL repair and reconstruction [47].

One limitation of this study is the method used to assess peak torque. The majority of previous studies have used an isokinetic dynamometer for the assessment of dynamic strength. However, isometric methods of strength assessment have been shown to be reliable when compared with Biodex isokinetic dynamometer testing, with inter- and intra-observer reliability of 0.98 and greater than 90% correlation [48,49]. Furthermore, the chosen knee position in this study allowed us to assess the peak hamstring torque at 90° of knee flexion. Most other studies have focused investigations at around 20°–30° of knee flexion, where maximal hamstring torque occurs; however, at that angle, there is more recruitment of the biceps femoris than the medial hamstrings [50]. This may therefore not always identify deficits caused as a result of medial hamstring harvest. Our testing protocol focuses on the area where the medial hamstrings, particularly the semitendinosus, are the main contributors [36,50].

There is also a limitation of the study design, being that patients were recruited posto-peratively and are therefore not randomly allocated to treatment arms. As such, pre-operative investigations were not possible as part of the study. Despite this, patient groups were well matched in terms of age, sporting performance, and activity level at the time of testing. It was not possible to control post-operative rehabilitation for any of the patients; however, it is recognised that patients undergoing ACL surgery receive early and regular physiotherapy input according to protocols approved by the senior clinicians. Additionally, the time interval from injury to surgery was not controlled, as the ACL repair procedure requires the injury to be addressed acutely, at least within three months. We suggest that the results of this study indicate that a well-designed, adequately powered, randomised controlled trial is warranted to investigate our findings further.

Conclusions

Deficits in hamstring strength seen following ACL reconstruction are not found after augmented ACL repair surgery, with potential for improved patient outcomes. Furthermore, ACL repair patients performed as well as or better in PROMs and laxity tests than matched patients following reconstruction, supporting the theory that this technique may be a viable alternative to reconstruction in appropriate patients.

Ethical approval

Ethical approval was obtained from University of Strathclyde ethics committee (UEC19/24) and the Northern Ireland Regional Ethics Committee (19/NI/0133).

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Gordon MacKay reports a relationship with Arthrex Inc. that includes: consulting or advisory and speaking and lecture fees.

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