Deficits in Muscle Strength Are Not Seen Following Recovery from Augmented Primary Repair of Anterior Cruciate Ligament Tears


PII: S2059-7754(23)00573-4
DOI: https://doi.org/10.1016/j.jisako.2023.09.008
Reference: JISAKO 165

To appear in: Journal of ISAKOS

Received Date: 12 December 2022
Revised Date: 6 September 2023
Accepted Date: 22 September 2023

Please cite this article as: Wilson WT, Banger MS, Hopper GP, Blyth MJG, MacKay GM, Riches PE, Deficits in Muscle Strength Are Not Seen Following Recovery from Augmented Primary Repair of Anterior Cruciate Ligament Tears, Journal of ISAKOS, https://doi.org/10.1016/j.jisako.2023.09.008.

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2023 Published by Elsevier Inc. on behalf of International Society of Arthroscopy, Knee Surgery and Orthopedic Sports Medicine.
Deficits in Muscle Strength Are Not Seen Following Recovery from Augmented Primary Repair of Anterior Cruciate Ligament Tears

W.T. Wilson¹², M.S. Banger¹, G.P. Hopper³, M.J.G. Blyth², G.M. MacKay⁴, P.E. Riches¹

¹ Department of Biomedical Engineering, University of Strathclyde, Glasgow, UK.
² Department of Orthopaedics, Glasgow Royal Infirmary, NHS Greater Glasgow & Clyde, UK.
³ Department of Trauma & Orthopaedics, NHS Lanarkshire University Hospitals, Glasgow, Scotland.
⁴ Rosshall Hospital, Glasgow, UK.

Corresponding Author: William Thomas Wilson; 07748098988; 2 Guthries Grove, Fenwick, Kilmarnock, UK, KA3 6GH; William.t.wilson@strath.ac.uk

Conflicts of interest: GM is a consultant for and receives royalties from Arthrex. The other authors have no disclosures.

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

Funding: This work was supported by grants from the British Association of Sport & Exercise Medicine and the West of Scotland Orthopaedic Research Society.
Deficits in Muscle Strength Are Not Seen Following Recovery from Augmented Primary Repair of Anterior Cruciate Ligament Tears
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 Knee Injury and Osteoarthritis Outcome Score (KOOS), Lysholm and Tegner scores. Maximal isometric quadriceps and hamstring strength at 90° knee flexion was 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 healthy volunteers by 0.29 Nm/kg. The hamstring strength ratio of operated to uninjured side was greater in the repair (95% ±13) than 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

Keywords: ACL, Repair, Reconstruction, Biomechanics, Strength, Hamstring

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 autologous tendon graft to replace the native ACL. Reconstruction using 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]. Arderen, Webster et al. [4] demonstrated hamstring weakness of up to 27% compared with the uninjured limb despite successful completion of rehabilitation. These asymmetric strength reductions can persist long after recovery with potential implications for neuromuscular control and function [3, 5, 6].

Realisation of the limitations of ACL reconstruction has led to renewed interest into 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, USA) [8]. Additionally, 20 healthy volunteers and 19 patients who had ACL reconstruction using ipsilateral hamstring autograft 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 by 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 on all participants after they indicated 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 scale. Knee stability was measured using 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 International Knee Documentation Committee (IKDC) classification.

**Strength testing**

Following a warm-up which consisted of two minutes of light jogging followed by ten body weight squats, maximal isometric quadriceps and hamstring strength was measured using a fixed myometer (MIE, Medical Research Ltd, UK). To do so, volunteers sat with their hip and knee flexed to 90° and were asked to attempt to flex and extend their knee as strongly as they could. A strap was attached to the leg, approximately 5-10 cm proximal to the medial malleolus (Figure 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 three seconds for each leg and with a minimum ten second rest in between each repetition. Torque was calculated by multiplying maximum force achieved by moment arm and normalised 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 drop out, we aimed to recruit 20 participants in each group, however there were no withdrawals. LSI was calculated by comparing operated to uninjured side. Using the uninjured side as a reference for assessing deficits to operated side is a commonly used and validated technique.
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, one-way ANOVA was used for parametric data, with 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 mean 4 years (±1.8) postoperatively for the repair group and mean 4 years (±1.5) postoperatively for the reconstruction group.

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 the healthy volunteers across all domains, and significantly lower than repair for KOOS activities of daily living (ADL) and also for Lysholm score (p<0.05) (Table 2). In contrast, the repair group scores were not different to healthy volunteers for KOOS pain, symptoms, ADL or Lysholm domains. There was no statistically significant difference between groups for current Tegner score; however there was a one point decrease in 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) (Figure 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 no difference as it pertains to quadriceps strength (101% v 105%, p=0.54) (Figure 2).

Group membership affected 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) (Figure 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 Rolimeter for 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 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, 5.7mm 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 ($p=0.03$).

**Discussion**

Realisation of the limitations associated with ACL reconstruction has prompted renewed interest into other techniques which 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]. Arden, 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 postoperatively. 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 postoperatively 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 who have persistent weakness compared to healthy subjects and asymmetry of lower limb strength.

Quadriceps and hamstring contraction has been shown to provide the majority of support for the knee adduction moment during walking [27] and is also vital for frontal plane stabilisation during sporting tasks [6]. Hamstrings act to prevent anterior tibial translation and rotation, functions which 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 return 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 were more commonly injured.

Quadriceps strength symmetry has been reported as an important factor to consider for
recovery following ACL reconstruction, even with 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 reassuring therefore 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 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 with contribution 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 which exceed the minimal clinically important difference. It should be noted however that patients selected for this study were those who were not known that 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 for 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 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° to 30° of knee flexion, where maximal hamstring torque occurs; however at that angle there is more recruitment of the biceps femoris rather 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 semitendinosus, are the main contributors [36, 50].

There is also a limitation of the study design, being that patients were recruited postoperatively and are therefore not randomly allocated to treatment arms. As such, preoperative 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 postoperative 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.
References


Response in Older, Active Patients: A Primary Anterior Cruciate Ligament Repair Technique. J Knee
18. Webster KE, Wittwer JE, O’Brien J, Feller JA. Gait Patterns after Anterior Cruciate Ligament
Reconstruction are Related to Graft Type. Am J Sports Med. 2005;33(2):247-
10.1177/0363546504266483.
on MRI, Flexor Strength, and Functional Performance After Anterior Cruciate Ligament
10.1177/0363546511424134.
20. Keays SL, Bullock-Saxton JE, Keays AC, Newcombe PA, Bullock MI. A 6-Year Follow-up of the
Effect of Graft Site on Strength, Stability, Range of Motion, Function, and Joint Degeneration after
10.1177/0363546506298277.
reconstruction: comparison between hamstring autograft, tibialis anterior allograft, and non-injured
22. Hiemstra LA, Webber S, Macdonald PB, Kriellaars DJ. Contralateral limb strength deficits
23. Moisala AS, Järvelä T, Kannus P, Järvinen M. Muscle strength evaluations after ACL
knee flexion and hamstring strength after anterior cruciate ligament reconstruction using hamstring
following anterior cruciate ligament reconstruction: A comparison between hamstrings and patella
tendon graft procedures on 45 patients. Acta Orthopaedica Scan. 2002;73(5):546-
52.10.1080/000164702321022820.
harvest on knee flexor strength after anterior cruciate ligament reconstruction. A detailed evaluation
27. Shelburne KB, Torry MR, Pandy MG. Contributions of muscles, ligaments, and the ground-
reaction force to tibiofemoral joint loading during normal gait. J Orthop Res. 2006;24(10):1983-
90.10.1002/jor.20255.
meeting six clinical discharge criteria before return to sport is associated with a four times greater
Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate
501.10.1177/0363546504269591.
31. Myer GD, Ford KR, Hewett TE. Rationale and Clinical Techniques for Anterior Cruciate
32. Knapik JJ, Bauman CL, Jones BH, Harris JM, Vaughan L. Preseason strength and flexibility


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

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

### Table 2: Average PROMs scores for each group

<table>
<thead>
<tr>
<th></th>
<th>Volunteer</th>
<th>Repair</th>
<th>Reconstruction</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOOS Pain *</td>
<td>100 (3)</td>
<td>97 (8)</td>
<td>94 (14)</td>
<td>0.018</td>
</tr>
<tr>
<td>KOOS Symptoms *</td>
<td>96 (10)</td>
<td>93 (18)</td>
<td>79 (18)</td>
<td>0.008</td>
</tr>
<tr>
<td>KOOS ADL *</td>
<td>100 (0)</td>
<td>100 (0)</td>
<td>99 (6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>KOOS Sport *</td>
<td>100 (0)</td>
<td>90 (10)</td>
<td>85 (20)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>KOOS QOL *</td>
<td>100 (5)</td>
<td>81 (38)</td>
<td>75 (25)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lysholm *</td>
<td>100 (5)</td>
<td>95 (15)</td>
<td>88 (7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Current Tegner Activity Score †</td>
<td>7.0 (±1.5)</td>
<td>6.2 (±1.9)</td>
<td>6.1 (±2.1)</td>
<td>0.2</td>
</tr>
</tbody>
</table>
* median (interquartile range) † mean (±SD). (KOOS: Knee injury and osteoarthritis outcome score, ADL: activities of daily living, QOL: quality of life)

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

<table>
<thead>
<tr>
<th>Strength</th>
<th>Volunteer</th>
<th>Repair</th>
<th>Reconstruction</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hamstring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak torque operated</td>
<td>n/a</td>
<td>0.81 (±0.18)</td>
<td>0.66 (±0.28)</td>
<td>0.002</td>
</tr>
<tr>
<td>(Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak torque uninjured</td>
<td>0.95 (±0.27)</td>
<td>0.87 (±0.22)</td>
<td>0.81 (±0.26)</td>
<td>0.35</td>
</tr>
<tr>
<td>(Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSI</td>
<td>n/a</td>
<td>95 (±13)</td>
<td>81 (±18)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(operated:uninjured %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Quadriceps</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak torque operated</td>
<td>n/a</td>
<td>1.38 (±0.43)</td>
<td>1.40 (±0.54)</td>
<td>0.72</td>
</tr>
<tr>
<td>(Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak torque uninjured</td>
<td>1.50 (±0.55)</td>
<td>1.40 (±0.39)</td>
<td>1.36 (±0.55)</td>
<td>0.39</td>
</tr>
<tr>
<td>(Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSI</td>
<td>n/a</td>
<td>101 (±22)</td>
<td>105 (±18)</td>
<td>0.54</td>
</tr>
<tr>
<td>(operated:uninjured %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instrumented Laxity</th>
<th>Knee Flexion (°)</th>
<th>Volunteer</th>
<th>Repair</th>
<th>Reconstruction</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of displacement</td>
<td>30</td>
<td>4.2 (±1.1)</td>
<td>3.9 (±1.0)</td>
<td>4.5 (±1.5)</td>
<td>0.4</td>
</tr>
<tr>
<td>operated side (mm)</td>
<td>90</td>
<td>4.5 (±1.5)</td>
<td>4.6 (±1.1)</td>
<td>5.7 (±1.7)</td>
<td>0.04</td>
</tr>
<tr>
<td>Side-to-side difference</td>
<td>30</td>
<td>0.3 (±1.1)</td>
<td>0.2 (±1.7)</td>
<td>0.4 (±1.1)</td>
<td>0.2</td>
</tr>
<tr>
<td>(operated-uninjured)</td>
<td>90</td>
<td>0.5 (±1.6)</td>
<td>0.3 (±1.6)</td>
<td>0.8 (±1.6)</td>
<td>0.03</td>
</tr>
<tr>
<td>(mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**(LSI: limb symmetry index)**

**Figure 1:** Photograph demonstrating setup for isometric quadriceps strength test using fixed myometer
Figure 2: Graph showing mean peak torque for quadriceps and hamstrings in each group; Operated/Uninjured leg for patient groups, Dominant/Non-dominant leg for volunteer group
**Declaration of interests**

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ 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. |