Strength deficits and flexion range of motion following primary anterior cruciate ligament reconstruction differ between quadriceps and hamstring autografts

Peta T Johnston,1 Julian A Feller,2 Jodie A McClelland,1 Kate E Webster1

ABSTRACT

Objective To determine if anterior cruciate ligament (ACL) reconstruction with a quadriceps tendon (QT) could achieve faster postoperative recovery compared with hamstring tendon (HT) ACL reconstruction.

Methods Thirty-seven QT patients were matched for gender, age and preinjury activity level with 74 HT patients. A 6-month postoperative assessment included standardised reported outcome measures: patient-reported outcome measures (PROMs) (International Kne e Documentation Committee-subjective knee evaluation form, Knee injury and Osteoarthritis Outcome Score-knee related quality of life subscale, ACL-Return to Sport after Injury scale, Marx activity scale, anterior knee pain), range of motion (active, standing and passive), anterior knee laxity testing, hop tests (single and triple crossover hop for distance) and isokinetic strength testing of the knee extensors and flexors. T-tests or Mann Whitney U tests were used to compare data between groups.

Results There were no significant differences between the two groups for any of the PROMs. The HT group had reduced active and standing knee flexion range compared with the QT group (p<0.001). Isokinetic strength testing showed significant deficits in limb symmetry indices for both concentric quadriceps peak torque at 60°/s (p<0.001) and 180°/s (p=0.01) in the HT group. There were significantly greater deficits in limb symmetry indices for concentric quadriceps peak torque at 60°/s (p<0.001) and 180°/s (p=0.001) in the QT group.

Conclusion The QT graft does not appear to offer a more rapid recovery in terms of knee symptoms or function which could have allowed for faster progression to the dynamic phases of rehabilitation.

Level of evidence Level III.

INTRODUCTION

The ultimate aim of anterior cruciate ligament (ACL) reconstruction is to allow people to return to their preinjury activities both competitively and safely.1 The time at which people return to sport following ACL reconstruction varies considerably and depends on many factors.2 3 Achieving early recovery of knee function after surgery allows the patient to progress to the more dynamic phases of rehabilitation leading to a reintroduction of sport specific exercises and activities.4 Reduced pain levels in the early postoperative period may allow for earlier activation and restoration of knee muscle function and strength and therefore facilitate an earlier progression to the next phases of rehabilitation. It has been suggested that early recovery, prior to 12 months following ACL reconstruction, may be superior with the quadriceps tendon (QT) graft due to a range of factors including less postoperative pain compared with other autografts.5

The QT graft has received increased attention as a viable option for ACL reconstruction with several studies showing comparable outcomes to the more commonly used hamstring tendon (HT) and patellar tendon (PT) grafts.6-8 Reported advantages for the utilisation of the QT include a satisfactory size,9 similar biomechanical properties to the native ACL,10 comparable knee joint stability to other autografts,8 and no disruption to the knee flexor mechanism. A recent systematic review11 found no significant differences in knee stability or graft failure rates between QT grafts compared with other graft types. Significantly better patient-reported function was, however, reported with the use of QT compared with HT. Studies with less than 12 months follow-up were excluded from this systematic review and results therefore do not include the early phase of recovery.8

The purpose of this study was to compare early recovery 6-months following ACL reconstruction using either a QT or a HT autograft. The hypothesis was that at 6-months postoperatively, the QT would demonstrate superior outcomes compared with the HT.

METHODS

Study design This was a matched cohort study.

What are the new findings?

- Comparable patient-reported outcome measures at 6 months following primary anterior cruciate ligament reconstruction with quadriceps tendon (QT) and hamstring tendon (HT) grafts.
- Knee strength differed between graft types at 6 months postoperatively with significantly greater quadriceps strength deficits found with QT, whereas HT demonstrated significantly greater hamstring strength deficits.
Participants
Patients for this matched cohort study were recruited from an existing larger longitudinal ACL reconstruction study which had obtained informed consent from all patients. All ACL reconstructions for patients included in this study were performed by an experienced knee surgeon between 2014 and 2018. Inclusion criteria for this study were: age 15–40 years, no previous surgery to either knee, no associated collateral ligament damage in the affected knee that required surgery or a modification of rehabilitation, no associated posterior cruciate ligament injury in the affected knee and no previous cruciate or collateral ligament with residual laxity in the opposite knee. In addition, patients who also had a lateral extra-articular tenodesis procedure at the time of primary ACL reconstruction were excluded.

Graft selection was made by the patient and in the case of minors, their family, after discussion of graft options with the treating surgeon and provided there was no contraindication to their choice, such as inadequate QT size based on body habitus and MRI appearances of the QT. QT grafts were not used in skeletally immature patients because of concern that patellar periosteum may be included in the graft construct which might potentially put the proximal tibial or distal femoral physes at risk. Many factors potentially influenced a patient’s choice, including previous experiences of friends and relatives, advice from primary care practitioners and media attention paid to professional athletes undergoing ACL reconstruction.

During the time of the study, the HT was the graft most frequently used by the treating surgeon. Due to a greater number of HT ACL reconstructions performed this study was able to employ a 1:2 matched ratio to increase statistical power. Each QT patient was individually matched for sex, age (±5 years) and preinjury activity level (frequent to high level sports) to two HT patients from the same longitudinal study, to help mitigate confounding variables. Thirty-seven patients who had an ACL reconstruction using a QT met the inclusion criteria and were matched with 74 patients who had a HT ACL reconstruction.

Surgical technique
All patients underwent an arthroscopically-assisted ACL reconstruction with the femoral tunnel drilled via the anteromedial portal. The QT graft was harvested as a soft tissue only graft in that no bone block from the patella was included (figure 1A). The width of the graft was 12 mm. The deep layer of the QT was kept intact and the thickness of the graft therefore varied from patient to patient. Because the graft was only partial thickness, the margins of the harvested site were not apposed, but if the joint was inadvertently entered, the tendon split was repaired with absorbable sutures. The maximal length that could be obtained without violating the rectus femoris muscle fibres was harvested. The desired minimum length was 7 cm but in some patients lengths less than this were accepted, including one patient whom a length of 6 cm was accepted. The smaller diameter end of the harvested tendon was attached to an EndoButton (Smith & Nephew, Andover, Massachusetts, USA) using two Ethibond (Johnson and Johnson, Ethicon, Guaynabo, Puerto Rico, USA) whipstitches and secured distally with an Ethibond whipstitch and fixed with a metallic interference screw (Arthrex, Naples, Florida, USA). For the HT graft, the semitendinosus and gracilis was harvested in a 1:1 ratio. The proximal end was attached to an EndoButton (Smith & Nephew, Andover, Massachusetts, USA) using two Ethibond whipstitches and secured distally with an Ethibond whipstitch and fixed with a metallic interference screw (Arthrex, Naples, Florida, USA). For the HT graft, the semitendinosus and gracilis was harvested in a 1:1 ratio. Table 1 shows patient characteristics.

Table 1  Patient characteristics*

<table>
<thead>
<tr>
<th></th>
<th>Quadriceps tendon</th>
<th>Hamstring tendon</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at surgery (years)†</td>
<td>20.0 (15–34)</td>
<td>20.5 (15–32)</td>
<td>N.S.</td>
</tr>
<tr>
<td>Gender (F/M)</td>
<td>8/29</td>
<td>16/58</td>
<td>N.S.</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178.2±7.6</td>
<td>178.4±9.1</td>
<td>N.S.</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.8±11.3</td>
<td>78.6±11.9</td>
<td>N.S.</td>
</tr>
<tr>
<td>Preinjury Marx scale†</td>
<td>16 (2–16)</td>
<td>13 (0–16)</td>
<td>N.S.</td>
</tr>
<tr>
<td>Time from injury to surgery: days†</td>
<td>49 (11–482)</td>
<td>59 (16–2143)</td>
<td>N.S.</td>
</tr>
<tr>
<td>Combined injury, none: MM: LM: both</td>
<td>17.8:11:1</td>
<td>35:12:15:12</td>
<td>N.S.</td>
</tr>
<tr>
<td>Graft diameter†</td>
<td>Proximal (mm)</td>
<td>8.0 (7–10)</td>
<td>N.S.</td>
</tr>
<tr>
<td></td>
<td>Distal (mm)</td>
<td>8.5 (7.5–10)</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

*Values are reported as mean±SD (range) unless noted otherwise.
†Mann-Whitney U-tests reported as median (range).
LM, lateral meniscus; MM, medial meniscus; N.S., not significant.
gracilis tendons were harvested and doubled over an EndoButton CL Ultra (Smith & Nephew). They were secured distally with an Ethibond whipstitch and fixed with a metallic interference screw (figure 1B).

Postoperative rehabilitation
All patients were given the same postoperative rehabilitation protocol. Weight bearing as tolerated was allowed immediately postoperatively and no braces or splints were used. Early restoration of full knee extension and quadriceps strength were encouraged. Progression through the rehabilitation programme was guided by the presence of pain and swelling. Patients were allowed to ride a stationary bike as soon as they were comfortable (usually between 3 and 4 weeks) and were allowed to commence gymnasium exercises from 5 weeks. Running was allowed once there was no knee effusion and quadriceps strength was satisfactory (usually from 12 to 16 weeks). Sport-specific drills were commenced from 4 months onwards.

Patient-reported outcome measures (PROMs)
Patients evaluated their knee recovery at 6 months using four validated patient reported outcome measures: International Knee Documentation Committee-subjective knee evaluation form (IKDC),13 14 the Knee injury and Osteoarthritis Outcome Score- knee related quality of life subscale (KOOS-QOL),15 the ACL-Return to Sport after Injury scale (ACL-RSI)16 and the Marx Activity Rating Scale (Marx).17 Patients were also asked if they had experienced any pain during the previous 4 weeks, both at the front of the knee or when kneeling (0=not at all, up to 10=worst imaginable).

Knee range of motion and laxity testing
Knee range of motion and anterior knee laxity were measured for both knees. Active knee flexion was measured in standing and in the lateral decubitus position. Passive knee flexion was measured in the lateral decubitus position. Passive knee extension deficits were measured according to the method described by Sachs et al.18 The difference in heel height was converted to degrees based on a formula using the patient’s height. The between limb difference (unaffected limb – operated limb) in active and passive knee range of motion was calculated. Anterior knee laxity was measured using a KT-1000 arthrometer (Medmetric, California, USA) as described by Daniel et al.19 The between limb difference (operated limb – unaffected limb) in anterior tibial displacement was recorded at 67 N and 134 N.

Hop testing
Hop testing consisted of a single hop and triple crossover hop for distance. Prior to data collection patients were allowed practice trials of each task. Patients then completed two trials of each task on each limb, with the average from two trials used to calculate a limb symmetry index (LSI) for each task (LSI=operated limb/unaffected limb×100).

Table 2  Patient-reported outcome measures*

<table>
<thead>
<tr>
<th>PROMs†</th>
<th>Quadriceps tendon</th>
<th>Hamstring tendon</th>
<th>P value</th>
<th>Effect size Cohen d</th>
</tr>
</thead>
<tbody>
<tr>
<td>IKDC-subjective‡</td>
<td>80.5 (36.8–97.7)</td>
<td>82.2 (54.0–100.0)</td>
<td>N.S.</td>
<td>0.20</td>
</tr>
<tr>
<td>ACL-RSI</td>
<td>58.6±23.7</td>
<td>58.2±19.7</td>
<td>N.S.</td>
<td>0.02</td>
</tr>
<tr>
<td>Marx scale</td>
<td>7.5±4.3</td>
<td>7.8±3.7</td>
<td>N.S.</td>
<td>0.08</td>
</tr>
<tr>
<td>KOOS-QOL</td>
<td>59.9±14.3</td>
<td>64.3±16.3</td>
<td>N.S.</td>
<td>0.04</td>
</tr>
<tr>
<td>Anterior knee pain†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incidence (%)</td>
<td>67</td>
<td>63</td>
<td>N.S.</td>
<td></td>
</tr>
<tr>
<td>Severity</td>
<td>2 (1–8)</td>
<td>3 (1–8)</td>
<td>N.S.</td>
<td></td>
</tr>
<tr>
<td>Pain with kneeling†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incidence (%)</td>
<td>83</td>
<td>81</td>
<td>N.S.</td>
<td></td>
</tr>
<tr>
<td>Severity</td>
<td>3 (1–7)</td>
<td>3 (1–9)</td>
<td>N.S.</td>
<td></td>
</tr>
</tbody>
</table>

*Values are reported as mean±SD unless noted otherwise.
†One QT patient did not have 6 month PROMs and was excluded from this analysis along with their two matched HT patients (QT=36, HT=72).
‡Mann-Whitney U-tests reported as median (range).
HT, hamstring tendon; IKDC, International Knee Documentation Committee; KOOS-QOL, Knee injury and Osteoarthritis Outcome Score- knee related quality of life subscale; N.S., not significant; PROMs, patient-reported outcome measures; QT, quadriceps tendon; RSI, Return to Sport after Injury scale.

Table 3  Knee range of motion and laxity testing*

<table>
<thead>
<tr>
<th>Between limb difference†</th>
<th>Quadriceps tendon</th>
<th>Hamstring tendon</th>
<th>P value</th>
<th>Effect size Cohen d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active knee flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing (°)‡</td>
<td>0.0 (–12 to 14) §</td>
<td>5.0 (–10 to 25)</td>
<td>&lt;0.001</td>
<td>0.88</td>
</tr>
<tr>
<td>Lateral decubitus (°)‡</td>
<td>–3.0 (–13 to 15)</td>
<td>4.5 (–13 to 28)</td>
<td>&lt;0.001</td>
<td>1.03</td>
</tr>
<tr>
<td>Passive knee flexion (°)‡</td>
<td>1.0 (–6 to 29)</td>
<td>4.5 (–17 to 28)</td>
<td>0.016</td>
<td>0.33</td>
</tr>
<tr>
<td>Extension deficit (°)</td>
<td>1.9±3.2</td>
<td>1.4±2.7</td>
<td>N.S.</td>
<td>0.17</td>
</tr>
<tr>
<td>Anterior knee laxity (67 N)‡</td>
<td>0.0 (–2 to 5)</td>
<td>0.3 (–3 to 4)</td>
<td>N.S.</td>
<td>0.00</td>
</tr>
<tr>
<td>Anterior knee laxity (134 N)</td>
<td>1.8±2.7</td>
<td>1.6±2.2</td>
<td>N.S.</td>
<td>0.08</td>
</tr>
</tbody>
</table>

*Values are reported as mean±SD unless noted otherwise.
†Positive values indicate a deficit in the operated limb.
‡Mann-Whitney U-tests reported as median (range).
§Significant difference between QT and HT (p<0.05).
HT, hamstring tendon; N.S., not significant; QT, quadriceps tendon.
were calculated for all outcomes using Cohen’s d, with a statistical significance set at \( p<0.05 \). Effect sizes were calculated using the HUMAC NORM Dynamometer (Computer Sports Medicine, Massachusetts, USA). Patients were positioned for strength testing in a seated position with the dynamometer chair back at an angle of 85° and the seat adjusted to the patient’s thigh length with the centre of rotation of the dynamometer aligned with the centre of rotation of the patients’ knee. The unaffected limb was tested first, followed by the operated limb. The limb being tested was secured to the seat using a set strap over the thigh. The test protocol consisted of the following two tests: (1) isokinetic concentric maximal knee extension and knee flexion contraction performed at 60°/s between full flexion and full extension and (2) isokinetic concentric maximal knee extension and knee flexion contraction performed at 180°/s between full flexion and full extension.

Two practice trials followed by three maximal contractions for test 1 and five maximal contractions for test 2 were completed. For each test, the LSI of mean peak torque was calculated as the operated limb compared with the unaffected limb.

**Statistical analysis**

An a priori power analysis using G*Power V.3.0.10 indicated that to detect a large effect size \( (d=0.8) \) for both knee extensor and flexor strength between QT and HT groups a sample size of at least 26 patients in each group was required to obtain 80% power with alpha set at 0.05.

IBM SPSS Statistics for Windows, V.25.0 (IBM, Armonk, New York, USA) was used to perform independent samples t-tests or Mann-Whitney U-tests between QT and HT ACL reconstruction groups, with a statistical significance set at \( p<0.05 \). Effect sizes were calculated for all outcomes using Cohen’s d, where \( d=0.8 \) is considered a large effect size. In the analysis of anterior knee pain and kneeling pain severity, only data from patients who reported pain were used. Patients who reported having no anterior knee pain or kneeling pain were treated as a missing data point as opposed to zero pain on the scale. Both the incidence and severity of anterior knee pain and kneeling pain were reported.

**RESULTS**

**Participants**

Patient characteristics for both QT and HT groups are displayed. Given that the groups were matched, there was no preoperative differences between groups with regard to age and preinjury Marx activity scores. Patients were participating in four main sports prior to ACL injury: Australian rules football/football (59%), soccer (12%), basketball (9%) and netball (9%). There were also no significant differences in relation to patients’ height, weight, time from ACL injury to surgery, combined meniscus injury rates and proximal and distal graft diameters between the two groups.

**Patient-reported outcome measures (PROMs)**

Six months postoperatively, there were no significant differences between the QT and HT groups for any of the PROMs (table 2). Most patients (72% QT; 58% HT) reported they were performing running or jogging activities at 6 months postoperatively, and 36% of both QT and HT patients had returned to training for their main sport.

**Knee range of motion and laxity testing**

The only significant differences between the QT and HT groups at 6 months were reduced active knee flexion range in standing \( (p<0.001) \), active knee flexion range measured in lateral decubitus \( (p<0.01) \) and passive knee flexion range \( (p=0.016) \) in the HT group compared with the QT group (table 3). No significant differences between the two groups were found for passive knee range of motion tests extension deficit and anterior knee laxity measured at 67 N or 134 N.

**Hop testing**

There were no significant differences in the limb symmetry indices for either single hop for distance or triple crossover hop for distance between the QT and HT groups (table 4).

**Isokinetic strength testing**

Isokinetic strength testing identified significant deficits in limb symmetry indices for concentric hamstrings peak torque at 60°/s and 180°/s between QT and HT groups (table 5). There were no significant differences between the QT and HT groups for any of the PROMs (table 2). Most patients (72% QT; 58% HT) reported they were performing running or jogging activities at 6 months postoperatively, and 36% of both QT and HT patients had returned to training for their main sport.

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<table>
<thead>
<tr>
<th>Table 4</th>
<th>Hop testing*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hop test</td>
<td>Limb symmetry index</td>
</tr>
<tr>
<td></td>
<td>Quadriceps tendon</td>
</tr>
<tr>
<td>Single hop for distance</td>
<td>92.8 (50.8–116.9)</td>
</tr>
<tr>
<td>Triple crossover hop for distance</td>
<td>95.1 (57.0–112.1)</td>
</tr>
</tbody>
</table>

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**Table 5 | Isokinetic strength testing***

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(p<0.001) and 180°/s (p=0.01) in the HT group. Significantly greater deficits in limb symmetry indices for quadriceps peak torque at 60°/s (p<0.001) and 180°/s (p=0.001) were seen in the QT group (table 5). The majority of patients in this study (69% of HT and 89% of QT) had not yet achieved a quadriceps muscle strength LSI>90%, whereas only 35% of QT patients compared with 70% of HT patients had not yet achieved a hamstring muscle strength LSI>90%.

DISCUSSION

Overall, the findings for this matched cohort study did not support the hypothesis that QT would be associated with superior outcomes 6 months following ACL reconstruction. Rather, the findings showed few differences between QT and HT autograft patients at 6 months after ACL reconstruction. The only differences between groups found to be statistically significant were greater active knee flexion and better hamstring muscle strength in QT patients and greater quadriceps muscle strength in the HT group. These differences were not unexpected given the site of graft harvest but would only have clinical implications if they persist in the longer term, especially at the time of return to sport.22

Despite finding greater quadriceps muscle strength with HT grafts compared with QT 6 months following ACL reconstruction, the median quadriceps strength LSI in the HT group was a modest 84%. The majority of patients in this study (69% of HT and 89% of QT) had not yet achieved a quadriceps muscle strength LSI>90%, a level which is often used as an indicator of satisfactory recovery of strength after ACL reconstruction. Previous studies have identified factors other than graft source that may affect knee extensor strength following ACL reconstruction, including quadriceps activation failure and deficits in knee extension range of motion.23 24 In the current study, both QT and HT groups demonstrated an extension deficit in the ACL reconstructed limb (QT: 1.9°; HT: 1.4°), and this potentially may have contributed to the reduced knee extensor strength outcomes found in both groups. Quadriceps strength LSI<90% prior to return to sport has been shown to be a significant predictor of knee reinjury.25 It is therefore important to continue to monitor quadriceps muscle strength beyond 6 months post-ACL reconstruction and focus on rehabilitation to ensure restoration of adequate strength.25

Both QT and HT groups in this study achieved over 90% LSI for both single hop and triple crossover hop for distance tests. Previous research following ACL reconstruction26 27 has found that adequate performance on a single hop for distance task does not necessarily correspond with adequate recovery of quadriceps muscle strength. The results of the current study are consistent with this in that satisfactory hop performance (LSI>90%) was achieved despite significant deficits in quadriceps muscle strength. A possible explanation is that patients are able to compensate for deficits in quadriceps muscle strength during hop testing by using other muscle groups in the kinetic chain, such as the calf, hip and trunk.

The current study also found a high proportion of patients, in both HT and QT groups, reported experiencing some pain either at the front of the knee or when kneeling, although the severity of knee pain in both groups was low (less than four measured using a 0–10 scale). Thus, the presence of anterior knee pain is not only associated with PT autografts28–30 but also with QT and HT grafts at least at a 6-month assessment. There were no differences between the two groups for patients’ self-evaluation of knee symptoms and function as measured by the IKDC subjective knee score. This may be in part related to the majority of HT and QT patients at 6 months having not yet returned to their preinjury sporting activities, as indicated by markedly lower Marx activity scores (QT=7.5; HT=7.8) compared with preoperatively (QT=16; HT=13). Specifically, 72% (26/36) of QT and 58% (43/74) of HT patients reported they were performing running or jogging activities (N.S.) and 36% of both QT and HT patients reported they had returned to training for their main sport at 6 months postoperatively. It is possible that despite a similar proportion of both QT and HT patients participating in running or jogging activities 6 months postoperatively, the quality of running or jogging performance differed between the two groups because of the reduced quadriceps muscle strength found with QT compared with HT ACL reconstruction. As previous research following ACL reconstruction has shown, knee strength deficits may negatively influence the quality of movement performance.31

Despite employing a well-matched cohort design to compare 6-month outcomes between HT and QT ACL reconstruction, the current study may not have matched patients for all relevant confounding variables. The matching criteria were sex, age and preinjury activity level. Other patient characteristics that could potentially influence our findings include height and weight, but these were not significantly different between the groups. Graft diameters were also similar between the groups. Although not every patient had a complete set of data, this study was sufficiently powered to detect large effects, between QT and HT groups, having more than the calculated minimum required sample size of 26 patients in each group.

Future research should investigate the longer-term recovery between QT and HT ACL reconstruction, particularly with regard to the recovery of knee extensor and flexor muscle strength. Recovery of sufficient knee strength following ACL reconstruction has been found to reduce knee reinjury,22 and it is therefore important to understand if and when knee strength deficits are restored following QT ACL reconstruction.

CONCLUSION

Based on the findings of this study, the QT graft does not appear to offer a more rapid recovery in terms of knee symptoms or function which could have allowed for faster progression to the dynamic phases of rehabilitation. Strength differences between the two groups can largely be attributed to the harvest site, but would only have clinical implications if they persist in the longer term, especially at the time of return to sport.

Contributors KEW, JAF and JAM conceived of the study and the acquisition of data and helped to draft the manuscript. PTI participated in the data analysis and performed statistical analysis and drafted the manuscript. All authors participated in critically revising the manuscript. All authors read and approved the final manuscript.

Funding This work was supported by an Australian Government Research Training Program Scholarship. Data collection for this study was completed by the research team at OrthoSport Victoria.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval Ethics approval was obtained from the relevant institutions (HEC19003 and HREC57012).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

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