Original Research

Strength symmetry after autograft anterior cruciate ligament reconstruction

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ABSTRACT

Objective: To compare postoperative isometric quadriceps strength indices (QI%) and hamstring strength limb symmetry indices (HI%) between partial thickness quadriceps tendon (pQT), full thickness quadriceps tendon (fQT), and bone-patellar-tendon bone (BPTB) autograft anterior cruciate ligament reconstruction (ACLR).

Methods: Patients with primary ACLR with pQT, fQT, or BPTB autograft with the documentation of quantitative postoperative strength assessments between 2016 and 2021 were included. Isometric Biodex data, including QI% and HI% (calculated as the percentage of involved to uninvolved limb strength) were collected between 5 and 8 months and between 9 and 15 months postoperatively.

Results: In total, 124 and 51 patients had 5–8- and 9–15-month follow-up strength data, respectively. No significant difference was detected between groups for sex. However, patients undergoing fQT were found to be older than those undergoing BPTB (24.6 ± 7 vs 20.2 ± 5; p = 0.01). There were no significant differences in the number of concomitant meniscus repairs between the groups (pQT vs. fQT vs. BPTB). No significant differences were detected in median (min–max) QI% between pQT, fQT, and BPTB 5–8 months [87% (44%–130%), 84% (44%–110%), 82% (37%–110%)] or 9–15 months [89% (50%–110%), 89% (67%–110%), and 90% (74%–140%)] postoperatively. Similarly, no differences were detected in median HI% between the groups 5–8 months or 9–15 months postoperatively.

Conclusion: The study was unable to detect differences in the recovery of quadriceps strength between patients undergoing ACLR with pQT, fQT, and BPTB autografts at 5–8 months and 9–15-months postoperatively.

Level of evidence: III.

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What are the new findings?

- The study was unable to detect differences in the recovery of quadriceps strength between patients undergoing anterior cruciate ligament reconstruction (ACLR) with partial thickness quadriceps tendon, full thickness quadriceps tendon and bone-patellar-tendon-bone autografts at 5–8 months and 9–15 months postoperatively.
- Study results suggest that the recovery of quadriceps strength symmetry appears to be similar between graft types. This knowledge may be important when choosing the graft type and planning the postoperative rehabilitation.

Introduction

Graft selection is a critical component of pre-operative planning for anterior cruciate ligament reconstruction (ACLR). Autografts are most common, with hamstring tendon (HT) and bone-patellar-tendon-bone (BPTB) autografts being the most frequent choices [1,2]. However, HT autografts have a higher failure rate in young, active individuals [3] than alternative options and BPTB autografts are associated with elevated rates of donor site morbidity [4]. These limitations of common autografts have led to an increased interest in quadriceps tendon (QT) autografts.

The QT autografts can be harvested as full or partial thickness grafts, with or without a bone block [5,6,7,8]. The QT provides a strong, stiff graft with failure rates lower than HT [9] and similar to BPTB autografts [10,11]. Furthermore, QT autografts result in lower donor site morbidity, especially with regards to anterior knee pain, than BPTB autograft [10].

Despite the promising results, QT autografts are not without limitations. The QT autografts have been shown to result in residual post-operative quadriceps weakness [12,13]. In a prior study, Hughes et al. found a greater degree of quadriceps strength asymmetry during the return-to-running phase of rehabilitation (5–8 months postoperatively) in patients with a full-thickness QT (fQT) autograft than patients with HT or BPTB autografts demonstrating greater quadriceps strength in patients with HT and BPTB compared to fQT [14]. Failure to achieve clinical milestones for quadriceps strength asymmetry can delay return to sport and place these individuals at increased risk of re-rupture [15,16,17,18,19,20].

Although, the fQT autograft has been associated with inferior post-operative quadriceps strength [14], there is a paucity of literature describing whether pQT is also associated with postoperative quadriceps strength weakness. A recent study reported similar postoperative quadriceps strength indices (QPI%) between fQT and pQT groups, but used pooled data including varying follow-up lengths, limiting the possibility for definitive conclusions [21]. Therefore, the purpose of this study was to compare postoperative isometric QPI% and hamstring strength limb symmetry indices (HPI%) between pQT, fQT, and BPTB autograft ACLR. We hypothesized that there would be no difference in quantitative measures of strength between ACLR performed with fQT or BPTB, while fQT ACLR would result in weaker postoperative QPI% and HPI%.

Methods

Study design

A retrospective chart-review of patients who underwent primary ACLR with QT (pQT and fQT) autograft and BPTB autograft was conducted. All patients, between 14 and 50 years of age, at a single institution between 2016 and 2021 with the documentation of quantitative postoperative isometric strength assessment via an electromechanical dynamometer (Biodex) performed at 60° of knee flexion (either 5–8 or 9–15 months postoperatively) were included. Exclusion criteria included ACLR with hamstring autograft or allograft, incomplete or inadequate postoperative isometric strength measurement data, double-bundle ACLR, posterolateral bundle augmentation, revision ACLR, previous contralateral ACLR, concomitant osteochondral and ligamentous procedures, osteotomy, and lateral extra-articular tenodesis. Patients undergoing meniscectomy and meniscal repair were included. Human subjects research approval was provided by the University of Pittsburgh Institutional Review Board (Study19030196). This study is presented according to the Strengthening the Reporting of Observational studies in Epidemiology guidelines [22].

Patient selection and data extraction

Patients who underwent ACLR between January 1st, 2016, and December 31st, 2021 were identified via query of the electronic medical record (EMR). Each patient record was reviewed by a single member of the research team for inclusion and exclusion criteria. After the patient was deemed eligible for inclusion, the medical record was reviewed for patient characteristics and outcomes of interest. Data extraction was completed by one of 6 reviewers for each record and entered into a Research Electronic Data Capture database [23].

Demographic data including sex, age at surgery (years), body mass index (BMI), mechanism of injury, time to surgery from injury, and time to strength testing from surgery were obtained via EMR review. Surgical variables collected included the use of a tourniquet and regional nerve block as well as concomitant meniscus repair or meniscectomy. Primary outcomes of interest were limb symmetry indices strengths in the forms of QPI% and HPI% calculated as the ratio of operative to non-operative peak torque knee extension and knee flexion, respectively.

Surgery and rehabilitation

Anatomic ACLR was performed by a sports medicine fellowship trained orthopaedic surgeon. Graft selection and characteristics (pQT vs. fQT, vs. BPTB), tunnel placement, and fixation method were at the discretion of the treating surgeon. All patients followed a standard graduated postoperative protocol which included supervised physical therapy with an emphasis on restoration of knee range of motion and quadriceps strength.

Quadriceps and hamstring strength testing

Study participants had completed isometric thigh and hamstring strength testing as part of routine clinical care and/or research study participation using a standardized protocol. To test quadriceps and hamstring strength, patients sat in the dynamometer with the hips flexed to 80° and the knee flexed to 60°. After a short warm-up, patients completed maximal isometric contractions of the quadriceps and hamstring strength, alternating between flexion and extension on each repetition with 30 s of rest between each session [24]. The isometric quadriceps and hamstring strength testing has previously been described in more detail by Hughes et al. [14].

Data reduction

The maximal torque output for the quadriceps and hamstring of each limb over three trials was recorded for analysis [14]. The maximal torque for each limb was used to calculate QPI% and HPI% (maximal torque for surgical limb/torque force for non-surgical limb) × 100 %. Previous literature has recommended that patients with 80 % symmetric postoperative quadriceps strength can generally return to running, while 90 % symmetric quadriceps strength is usually required for returning to play [25,26,27]. Strength outcomes measurements were grouped at 2
time points, 5–8 and 9–15 months postoperatively to represent strength measurements in the late rehabilitation (initiation of running and jumping activities) and return-to-play phases, respectively. If a participant had multiple strength testing results within the time window of interest, the latest (most recent) test was used for analyses.

Statistical analysis

Demographics, surgical data, and QI% and HI% were compared amongst the 3 graft types at both 5-8-month and 9–15-month postoperative time ranges. Continuous variables were tested with the Kruskal–Wallis test, and categorical variables were tested with the chi-squared test or Fisher’s exact test. Post-hoc comparisons were adjusted with the Benjamini-Hochberg procedure, and effect sizes were calculated using Cohen’s d. Continuous variables were presented using mean and standard deviation or median and minimum/maximum values and binary and categorical variables were summarized using counts (n) and proportions (%).

Results

Participants

During the study period, a total of 338 patients underwent ACLR with BPTB and 588 underwent ACLR with QT. After exclusion criteria were applied, 124 patients met inclusion criteria with 5-8-month postoperative isometric Biodex testing (Table 1). Sixty (60) patients underwent pQT autograft ACLR, 19 underwent fQT autograft ACLR, and 45 underwent BPTB autograft ACLR. No significant differences were detected between groups for sex, percent of sports-related injuries, as well as time to surgery or isometric Biodex testing. Patients undergoing fQT were older than those undergoing BPTB (Table 1; p = 0.01), and patients undergoing pQT had lower BMI than those undergoing BPTB (Table 1; p = 0.03). Patients with QT autografts appeared to have longer tourniquet time than patients undergoing pQT (Table 1; p = 0.049), and patients undergoing BPTB were less likely to receive preoperative regional analgesic nerve block than patients undergoing pQT (Table 1; p = 0.003).

A total of 51 patients met inclusion criteria with 9–15-month postoperative isometric Biodex testing (Table 2). Twenty-six (26) patients underwent pQT autograft ACLR, 10 underwent fQT autograft ACLR, and 15 underwent BPTB autograft ACLR. No significant differences were detected between groups for age at surgery, sex, BMI, percent of sports-related injuries, time to surgery or isometric Biodex testing, intraoperative tourniquet time, or percent of patients undergoing concomitant ipsilateral meniscectomy or meniscal repair. Patients undergoing BPTB were less likely to receive preoperative regional analgesic nerve block than patients undergoing fQT (Table 2; p = 0.04).

Late rehabilitation phase (5–8 months)

No statistical difference was detected in QI% between pQT, fQT, or BPTB at 5–8 months postoperatively (Table 3; p = 0.41). Similarly, no statistical difference was observed in HI% between pQT, fQT, and BPTB at 5–8 months postoperatively (Table 3; p = 0.55).

Return-to-sport phase (9–15 months)

No statistical difference was detected in QI% between pQT, fQT, or BPTB at 9–15 months postoperatively (Table 4; p = 0.22). Similarly, no statistical difference was observed in HI% between pQT, fQT, and BPTB at 9–15 months postoperatively (Table 4; p = 0.35).

Discussion

This study was unable to detect differences in QI% or HI% between patients undergoing ACLR with pQT, fQT, and BPTB at the return-to-running (5–8 months) or return-to-sport phases (9–15 months) of postoperative rehabilitation. This suggests that within the study population, recovery of quadriceps strength symmetry appear to be similar between graft types. This supports the first part of the study hypothesis, that there would be no difference in quantitative measures of strength between ACLR performed with pQT or BPTB. However, contrary to the second part of the hypothesis, there were also no statistical differences detected in postoperative QI% and HI% in patients undergoing fQT autograft ACLR compared to those that underwent ACLR with pQT or BPTB autografts.

Variable results exist in the literature on QT autograft ACLR’s effect on postoperative strength recovery [14,17,21,28,29]. A 2019 systematic review pooling heterogeneous data from 18 studies found that fQT autograft ACLR resulted in similar patient reported outcomes and complications as pQT autograft ACLR [21]. However, a 2023 cohort study

Table 1
Demographic and operative data for patients with isometric Biodex testing 5–8 months postoperatively.

<table>
<thead>
<tr>
<th>Variable</th>
<th>pQT (n = 60)</th>
<th>fQT (n = 19)</th>
<th>BPTB (n = 45)</th>
<th>Overall p-value</th>
<th>pQT vs fQT p-value</th>
<th>pQT vs BPTB p-value</th>
<th>fQT vs BPTB p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at surgery (years)</td>
<td>22.2 ± 7.5</td>
<td>24.6 ± 7.3</td>
<td>20.2 ± 5.2</td>
<td>0.04</td>
<td>0.15</td>
<td>0.48</td>
<td>0.01</td>
</tr>
<tr>
<td>BMI, median ± SD; median (min-max)</td>
<td>19.6 (14.2–42.5)</td>
<td>23.4 (14.3–45.6)</td>
<td>20.2 (14.4–40.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to surgery (months)</td>
<td>2.9 ± 9.7</td>
<td>11.7 ± 36.0</td>
<td>5.0 ± 14.9</td>
<td>0.08</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Time to biopsy (months postoperatively)</td>
<td>1.1 (0.0–75.6)</td>
<td>1.7 (0.59–159.5)</td>
<td>1.3 (0.16–97.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tourniquet time (minutes)</td>
<td>90.2 ± 19.4</td>
<td>104.8 ± 21.8</td>
<td>97.1 ± 18.3</td>
<td>0.21</td>
<td>0.04</td>
<td>0.09</td>
<td>0.17</td>
</tr>
<tr>
<td>Regional block (yes), n (%)</td>
<td>31 (53)</td>
<td>33 (68)</td>
<td>30 (67)</td>
<td>0.002</td>
<td>0.22</td>
<td>0.01</td>
<td>0.003</td>
</tr>
<tr>
<td>Sex (male), n (%)</td>
<td>30 (50)</td>
<td>14 (74)</td>
<td>30 (67)</td>
<td>0.09</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Meniscectomy, n (%)</td>
<td>8 (13)</td>
<td>7 (37)</td>
<td>7 (16)</td>
<td>0.06</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Meniscal repair, n (%)</td>
<td>37 (62)</td>
<td>10 (53)</td>
<td>26 (58)</td>
<td>0.77</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sport-related injury (yes), n (%)</td>
<td>58 (97)</td>
<td>19 (100)</td>
<td>39 (87)</td>
<td>0.09</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

BMI = body mass index; BPTB = bone-patellar-tendon-bone; fQT = full thickness quadriceps tendon; pQT = partial thickness quadriceps tendon; SD = standard deviation.

* Tourniquet time was not available for the complete cohort, and it is unknown whether those who were missing tourniquet time had a tourniquet used on them. Values reported are based on sample sizes of 59, 13, and 38 for pQT, fQT, and BPTB, respectively.
examined strength recovery in fQT and pQT autograft ACLR in the operative limb compared to the non-operative limb at follow-up points >1 year after surgery [30]. The authors found that patients undergoing pQT autograft ACLR recovered quadriceps muscle function (peak torque, power, total work) at final follow-up [30]. However, patients undergoing fQT autograft ACLR did not recover quadriceps muscle function at final follow-up compared to the nonoperative limb [30]. Furthermore, a 2019 retrospective study conducted at the same institution as this present study enrolled patients from 2010 to 2015 and compared strength outcomes of fQT autograft ACLR, BPTB autograft ACLR, and hamstring autograft ACLR concluded that clinically meaningful quadriceps strength asymmetry remained at both 5–8 month and 9–15 month postoperative follow-up points in patients undergoing fQT autograft ACLR. This current study, enrolling patients from 2016 to 2021, found no significant difference in %QI between pQT, fQT, and BPTB groups. Although no direct comparisons were made between patients in the 2019 study [14] and this current study, proposed explanations for differing results in fQT autograft ACLR %QI outcomes both at 5–8 month (69.5% ± 17.4% vs. 84% ± 15%) and 9–15 month (83.3% ± 20.7% vs. 90% ± 14%) follow-up timepoints include improved operative technique in graft harvesting and an increased focus on quadriceps strengthening in postoperative physical therapy protocols due to greater awareness of deficits in quadriceps strength following fQT autograft [31].

While quadriceps strength recovery is crucial for patients after ACLR [16], less is known about the role of hamstring strength in postoperative recovery. In general, previous studies have reported weaker hamstring strength in patients undergoing ACLR with HT [32,17]; however, our study population only included patients treated with pQT, fQT, or BPTB. Not surprisingly, no significant difference regarding HI% was found between patients undergoing ACLR with pQT autograft, fQT autograft and BPTB autograft at the 5–8-month or 9–15-month follow-ups. These results are in line with previous literature reporting hamstring strength in patients undergoing QT autograft ACLR and BPTB autograft ACLR [32].

There were several important limitations to acknowledge with this study. First, this was a retrospective chart review study. Therefore, sample size was limited by the availability of post-operative strength measures that fell within the time periods of interest. Third, the use of a limb symmetry index can be influenced by the strength of the uninvolved limb, resulting in an underestimation or overestimation of quadriceps strength recovery. Regardless, we chose to examine limb symmetry indexes as they are the most commonly reported metric of strength recovery, are utilized as clinical milestones for progression of rehabilitation, and help control for difference between patients, such as bodyweight or sports participations, which may influence strength outcomes. Fourth, the timepoints for strength testing were not standardized, as they were completed as part of routine clinical care. Finally, not all patients that underwent strength testing at the earlier timepoint were tested again at the later timepoint. In our clinical experience, elite athletes or individuals struggling to recover strength are most likely to

Table 2
Demographic and operative data for patients with isometric Biodex testing 9–15 months postoperatively.

<table>
<thead>
<tr>
<th></th>
<th>9–15-month follow-up</th>
<th>Overall p-value</th>
<th>pQI vs fQI p-value</th>
<th>pQI vs BPTB p-value</th>
<th>fQI vs BPTB p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pQT (n = 26)</td>
<td>pQT (n = 10)</td>
<td>BPTB (n = 15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at surgery (years), mean ± SD; median (min–max)</td>
<td>21.2 ± 5.9 (18.5)</td>
<td>26.2 ± 7.8 (20.0)</td>
<td>19.6 ± 3.4 (17.8)</td>
<td>0.10 NA NA NA</td>
<td></td>
</tr>
<tr>
<td>BMI, mean ± SD; median (min–max)</td>
<td>25.1 ± 5.1 (23.7)</td>
<td>27.5 ± 7.2 (25.4)</td>
<td>23.9 ± 3.2 (23.2)</td>
<td>0.57 NA NA NA</td>
<td></td>
</tr>
<tr>
<td>Time to surgery (months), mean ± SD; median (min–max)</td>
<td>2.8 ± 4.0 (1.4)</td>
<td>19.0 ± 49.6 (1.6)</td>
<td>8.4 ± 24.9 (1.3)</td>
<td>0.16 NA NA NA</td>
<td></td>
</tr>
<tr>
<td>Time to biodex (months postoperatively), mean ± SD; median (min–max)</td>
<td>10.9 ± 1.7 (10.2)</td>
<td>11.0 ± 1.2 (11.3)</td>
<td>10.7 ± 1.0 (10.5)</td>
<td>0.74 NA NA NA</td>
<td></td>
</tr>
<tr>
<td>Tourniquet time* (minutes), mean ± SD; median (min–max)</td>
<td>98.4 ± 16.6 (90.0)</td>
<td>111.7 ± 14.2 (120.0)</td>
<td>100.6 ± 13.7 (100.0)</td>
<td>0.06 NA NA NA</td>
<td></td>
</tr>
<tr>
<td>Regional Block (yes), n (%)</td>
<td>18 (69)</td>
<td>9 (90)</td>
<td>5 (36)</td>
<td>0.02 0.39 0.06 0.04</td>
<td></td>
</tr>
<tr>
<td>Sex (male), (%)</td>
<td>14 (54)</td>
<td>3 (30)</td>
<td>8 (53)</td>
<td>0.41 NA NA NA</td>
<td></td>
</tr>
<tr>
<td>Meniscectomy, n (%)</td>
<td>7 (27)</td>
<td>2 (20)</td>
<td>1 (7)</td>
<td>0.57 NA NA NA</td>
<td></td>
</tr>
<tr>
<td>Meniscal repair, n (%)</td>
<td>16 (62)</td>
<td>5 (50)</td>
<td>10 (67)</td>
<td>0.70 NA NA NA</td>
<td></td>
</tr>
<tr>
<td>Sport-related injury (yes), n (%)</td>
<td>23 (88)</td>
<td>9 (90)</td>
<td>13 (87)</td>
<td>1.00 NA NA NA</td>
<td></td>
</tr>
</tbody>
</table>

BMI = body mass index; BPTB = bone-patellar-tendon-bone; fQT = full thickness quadriceps tendon; pQT = partial thickness quadriceps tendon; SD = standard deviation.

* It is unknown whether those who were missing tourniquet time had a tourniquet used on them.

Table 3
Strength testing data for patients with isometric Biodex testing 5–8 months postoperatively.

<table>
<thead>
<tr>
<th></th>
<th>5–8-month follow-up</th>
<th>Overall p-value</th>
<th>pQI vs fQI p-value</th>
<th>pQI vs BPTB p-value</th>
<th>fQI vs BPTB p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pQT (n = 60)</td>
<td>pQT (n = 19)</td>
<td>BPTB (n = 45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QI% Mean ± SD; median (min–max)</td>
<td>85 ± 18.87 (44-130)</td>
<td>84 ± 15.94 (44-110)</td>
<td>80 ± 17.82 (37-110)</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>HI% Mean ± SD; median (min–max)</td>
<td>93 ± 19.83 (46-160)</td>
<td>100 ± 19.96 (73-140)</td>
<td>94 ± 17.93 (61-150)</td>
<td>0.55</td>
<td></td>
</tr>
</tbody>
</table>

BPTB = bone-patellar-tendon-bone; fQT = full thickness quadriceps tendon; HI% = hamstring index; pQT = partial thickness quadriceps tendon; QI% = quadriceps index.

Table 4
Strength testing data for patients with isometric Biodex testing 9–15 months postoperatively.

<table>
<thead>
<tr>
<th></th>
<th>9–15-month follow-up</th>
<th>Overall p-value</th>
<th>pQI vs fQI p-value</th>
<th>pQI vs BPTB p-value</th>
<th>fQI vs BPTB p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pQT (n = 26)</td>
<td>pQT (n = 10)</td>
<td>BPTB (n = 15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QI% Mean ± SD; Median (min–max)</td>
<td>82 ± 16 (89-50-110)</td>
<td>90 ± 14 (89-57-110)</td>
<td>96 ± 18 (90-74-140)</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>HI% Mean ± SD; Median (min–max)</td>
<td>96 ± 18 (92-44-120)</td>
<td>102 ± 11 (100-90-120)</td>
<td>105 ± 24 (98-77-170)</td>
<td>0.36</td>
<td></td>
</tr>
</tbody>
</table>

BPTB = bone-patellar-tendon-bone; fQT = full thickness quadriceps tendon; HI% = hamstring index; pQT = partial thickness quadriceps tendon; QI% = quadriceps index.
receive repeat testing. Thus, there may have been an unintentional se-
lection bias in our later follow-up period.

Conclusions

The study was unable to detect differences in recovery of quadriceps
or hamstring strength between patients undergoing ACLR with pQT, iQT,
and BPT autografts 5–8 months or 9–15 months postoperatively. Pro-
spective studies with larger sample sizes are needed to determine if
clinically meaningful differences in quadriceps or hamstring strength
exist between these graft types at the mid-to late-rehabilitation phases.

Author contributions

All listed authors have contributed substantially to this work: litera-
ture search, and primary manuscript preparation were performed by JK,
ZH, NPD, RR, and EMZ. CS assisted with the statistical analyses. JDH,
BPL, JJJ, VM, and AL assisted with study design, interpretation of the
results, as well as editing and finalizing the manuscript. All authors have
read and approved the final manuscript to be submitted and published.

Ethical considerations

Human subjects research approval was provided by the University
of Pittsburgh Institutional Review Board (Study19030196).

Conflict of interest

The authors declare the following financial interests/personal re-
lationships which may be considered as potential competing interests:
Lesniak P Bryson reports a relationship with Mid-Atlantic Surgical
Systems that includes: education. James J Irrgang reports a relationship
with the Journal of Orthopaedic and Sports Physical Therapy that in-
cludes: President-Elect of the Board of Directors. Volker Musahl reports a
relationship with Smith and Nephew Inc that includes: consulting or
educational grants. Volker Musahl reports a relationship with Arthrex Inc that includes: educational grants.

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