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Knee pain associated with bone–patellar tendon–bone autografts does not limit activity levels, sports participation or quality of life after ACL reconstruction

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Abstract

Purpose: Bone–patellar tendon–bone (BPTB) and Hamstring (HT) autografts are commonly used for anterior cruciate ligament reconstruction (ACLR). Concerns exist regarding postoperative anterior knee pain (AKP) and kneeling discomfort with BPTB grafts. However, many studies solely report the presence/absence of anterior knee pain, without assessing its clinical significance in terms of functional limitation or impact on quality of life.

Methods: This study prospectively analysed 1407 patients undergoing primary ACLR with BPTB or HT autografts. Knee pain prevalence, severity, and location were measured at 6 months, 1 year, 2 years, and 5 years postoperatively using a pain questionnaire. Patient-reported measures (Knee Injury and Osteoarthritis Outcome Score [KOOS], Western Ontario and McMaster Universities Osteoarthritis Index [WOMAC], International Knee Documentation Committee [IKDC] and Marx) and return to play (RTP) rates were also collected to evaluate knee symptoms, function and activity levels. Multivariable regression identified factors associated with knee pain at each time point.

Results: The mean age was 24.5 ± 7.1 years, with 74.3% male. BPTB grafts were used in 81% ($n = 1145$) and HT in 19% ($n = 262$). At 6 months, the BPTB group reported a higher prevalence of AKP (26% vs. 6%, $p < 0.001$). There was no difference between graft types at 1 year and 2 years postoperatively. At 5 years, the BPTB group were 1.59 times more likely to report pain, although most pain was mild and there was no significant differences in KOOS, WOMAC, IKDC, Marx scores or RTP rates. Female patients (OR 1.41, $p < 0.035$) and BPTB grafts (OR 1.78, $p < 0.004$) were associated with knee pain at 6 months. At 5 years, older age (OR 1.06, $p < 0.001$), BPTB grafts (OR 1.59, $p < 0.027$), and medial femoral condyle chondral pathology (OR 1.7, $p < 0.020$) increased the odds of having pain.

Conclusion: BPTB grafts are associated with early AKP, which improves over time. AKP related to BPTB is mild and does not affect activity levels,

Abbreviations: ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; BPTB, bone–patellar tendon–bone; CKP, consequential knee pain; HT, hamstring; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; LFC, lateral femoral condyle; LTP, lateral tibial plateau; MFC, medial femoral condyle; MTP, medial tibial plateau; PFJ, patellofemoral joint; RTP, return to play; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

sports participation or quality of life. Mild AKP should not deter surgeons from using BPTB autografts for ACLR, given the other advantages of this graft choice.

Level of Evidence: Level II, prospective study.

KEYWORDS

5 years, anterior cruciate ligament, anterior knee pain, bone–patellar tendon–bone, hamstring autograft

INTRODUCTION

Bone–patellar tendon–bone (BPTB) and Hamstring (HT) autografts are the two most commonly used grafts for anterior cruciate ligament reconstruction (ACLR) [2]. Recent studies have shown that BPTB autografts have lower graft re-injury rates and higher return to sport rates compared to HT autografts, especially in young patients who participate in pivoting sports [26, 37, 49]. Proponents of BPTB autografts also cite the advantages of improved rotational stability and rapid graft incorporation through bone-to-bone healing [1, 15]. However, the widespread use of BPTB autografts is tempered by concerns over anterior knee pain (AKP) and kneeling discomfort [32, 50]. In contrast, HT autografts preserve the extensor mechanism but have been associated with graft elongation over time, knee flexion weakness, tunnel widening and damage to the infrapatellar branch of the saphenous nerve [5, 16].

Critical appraisal of the literature reveals that the association between BPTB autografts and AKP is not well understood. The reported incidence of AKP associated with BPTB grafts varies dramatically in Level 1 studies, ranging from 5.4% to 48.4% [30]. Additionally, there are now several randomised trials that have demonstrated minimal differences in symptomatic outcomes between BPTB and HT autografts at various post-operative time-points [14, 18, 27, 36, 45]. On the other hand, earlier studies by Zaffagnini et al. [50] and Pinczewski et al. [32] have reported that BPTB grafts were associated with increased harvest site symptoms at 5 and 10 years follow-up.

It is likely that inconsistencies between previous studies stem from the variety in surgical techniques, rehabilitation quality and the methodology used to assess pain. Several studies use a single measure or binary classification to assess pain, which fails to capture its inherently complex and multifactorial nature. Few studies have contextualised the clinical significance of pain in terms of its impact on activity levels, sports participation, or quality of life. This is particularly important, as patellofemoral pain represents the most commonly reported symptom among uninjured athletic populations, especially younger individuals participating in pivoting and cutting sports [28, 48]. More recently, the concept of 'consequential knee pain' has gained traction, aiming to capture persistent discomfort that significantly impairs function and overall well-being [33, 44]. Compounding these gaps, there is a lack of longitudinal data examining the progression of pain and functional outcomes over time.

The primary objective of this study was to longitudinally document the prevalence, severity and location of knee pain over 5 years in a consecutive cohort of patients who underwent primary ACLR. Importantly, we aimed to thoroughly evaluate the clinical significance of this pain by using multiple measures of symptoms and function at each time point (6 months, 1 year, 2 years and 5 years). Additionally, the outcomes of BPTB and HT autografts were compared to determine the influence of graft choice on knee pain. The secondary objective of this study was to identify which demographic (age and sex), injury-related (mechanism of injury), and clinical (meniscal injuries, chondral pathology and ACL-RSI score) factors were associated with the presence of knee pain.

METHODS

Patient cohort

Participants were prospectively enroled between 1 January 2014 and 31 September 2016 from the caseload of two sub-specialist orthopaedic knee surgeons (R.M. and M.J.). Patients were included if they were aged between 13 and 45 years and were undergoing primary ACL reconstruction (ACLR), including those with a previous contralateral injury. We excluded those who underwent revision ACLR or multi-ligament knee repair/reconstruction. Patients were also excluded if they had undergone previous meniscal surgery to the ipsilateral knee or underwent a concurrent lateral extra-articular tenodesis. All participants provided informed consent before data collection commenced and our local ethical review board approved this study. The reporting of this study followed the 'Strengthening the Reporting of Observational Studies in Epidemiology' (STROBE) guidelines [10].

Surgical procedure

The surgical procedures were all performed using equivalent arthroscopic and surgical techniques, utilising either BPTB or HT autografts. The surgeons determined graft selection based on their assessment of a patient's demographics and physical examination findings. BPTB grafts were predominantly used given the surgeons' preference for this graft type in patients returning to pivoting sports. Contraindications to BPTB grafts included a history of patellar tendinopathy or the presence of open physis, whereas contraindications to HT grafts included prior HT injuries or if the patient relied heavily on sprinting. The BPTB grafts were harvested from the central third of the patellar tendon with two bone blocks and secured using metal interference screws (Softsilk; Smith & Nephew, Watford, UK). The patellar tendon defect and paratenon were closed in one layer using two interrupted sutures with additional bone grafting of the patellar harvest site. HT grafts were fixed using an EndoButton (CL Ultra; Smith & Nephew, Watford, UK) for femoral fixation and a non-absorbable screw (Biosure PK; Smith & Nephew, Watford, UK) for tibial fixation. Tunnel positions were placed at the anatomical footprints of the original ACL and femoral drilling was performed through an anteromedial portal. During the surgical procedure, routine arthroscopy was performed to address any co-existing meniscal or chondral pathology, which was treated accordingly.

Rehabilitation

Postoperatively, patients were immediately permitted to weight-bear as tolerated without a brace. Crutches were used for approximately the first two weeks. Follow-up assessments were scheduled with the surgeons at regular intervals after surgery. Due to the geographical distribution of the participants, the majority were supervised by their local rehabilitation specialist. As part of the postoperative assessment, participants attended our institution and underwent several reactive strength and change of direction tests to track the progress of their rehabilitation. During these visits, the orthopaedic surgeon advised all participants to focus on restoring strength and power (at least 90% limb symmetry index) before considering returning to play. Clearance to return to competitive sport was typically between 9 and 12 months postoperatively and was determined by the treating surgeon and rehabilitation specialist. Return to play in this study was defined as the unrestricted resumption of a patient's pre-injury sport [19].

Outcome measures: Pain and function

The primary outcome measured in this study was the prevalence and severity of knee pain at 6 months, 1 year, 2 years and 5 years postoperatively. This was assessed using a standardised questionnaire that consisted of a dichotomous 'Yes/No' item to indicate the presence of knee pain, a multiple choice question specifying the location of the pain (anterior, posterior, medial and lateral) and a numerical rating scale (NRS) to assess pain severity (1–10). We defined mild pain as a score between 1 and 3, moderate pain as a score between 4 and 6 and severe pain as a score between 7 and 10 [40].

The other outcome measures for this study were selected to give a comprehensive, multi-dimensional assessment of knee function, symptoms, quality of life and activity levels. The International Knee Documentation Committee Subjective Form (IKDC) [19] and the Marx Activity Rating Scale [25] were recorded at each time point to provide an overview of the participants' knee function and activity levels, respectively. The IKDC also assesses knee-specific symptoms including pain and ability to perform tasks such as kneeling [17]. The Marx Activity Rating Scale complements this by recording the frequency of high-demand manoeuvres performed (running, cutting, decelerating and pivoting) [22]. At 5 years follow-up, patients completed the Knee Injury and Osteoarthritis Outcome Score (KOOS) [34] and Western Ontario McMaster Universities Osteoarthritis Index (WOMAC) [3] scores. For this study, the KOOS score was reported as five individual subscales (pain, symptoms, activities of daily living, sports and quality of life). Each subscale was summed and transformed into a zero (worst possible) to 100 (best possible) score. 'Consequential knee pain (CKP)' was set at a score of ≤ 72 points on the KOOS pain subscale as per the MOON group's definition [44]. Similarly, the WOMAC score was reported as three individual subscales (pain, stiffness and function) and a total score from zero (worst possible) to 100 (best possible). Patients were also asked to report if they had returned to their pre-injury sport since surgery.

Factors associated with knee pain

All participants completed a preoperative questionnaire, which collected data regarding their age, sex, level of sports participation before injury, primary mechanism of injury, Marx Activity Scale score and ACL return to sport after injury scale (ACL-RSI) [46]. Intraoperative data including the type of graft, grade of chondral injuries and treatment for meniscal injuries (left in situ, meniscectomy and repair) were recorded during surgery. Multivariable analysis of the preoperative and intraoperative factors associated with pain was performed.

Statistical analysis

Patient demographics were reported as descriptive statistics. Continuous variables were displayed as mean (standard deviation [SD]) whereas categorical variables were displayed as numbers and percentages. The prevalence and location of pain were compared between graft types using the chi-squared test. Patient-reported outcome measures (IKDC, KOOS, WOMAC and Marx) were compared using the non-parametric Mann–Whitney *U* test, given the non-normal distribution of scores. Where statistically significant differences were observed between groups, Cohen's *d* was calculated to quantify the magnitude of between-group effects for continuous outcomes, using pooled standard deviations. Effect sizes were interpreted according to standard thresholds (small ≤ 0.2, medium ≤ 0.5 and large ≤ 0.8) [8].

Multivariate logistic regression was used to identify factors associated with postoperative knee pain at each time point. All clinically relevant variables including age, sex, mechanism of injury, graft type, chondral injury, meniscal injury, preoperative ACL-RSI score and Marx score were entered into a forward stepwise regression model. Therefore, in our multivariable analysis, each independent variable (e.g., age and sex) was adjusted for in the model to determine which factors were independently associated with the presence of pain. Results were reported as odds ratio (OR) and 95% confidence intervals. The threshold for statistical significance was set at a *p*-value < 0.05. Data analysis and graphical presentation were performed using STATA version 18.0 (StataCorp LP, College Station, TX, USA).

RESULTS

A total of 1627 primary ACLRs met the inclusion criteria. There were 1407 participants remaining after the exclusion criteria were applied. The patient demographic information is shown in Table 1. Data was available for 94.4% (1328/1407) of patients at 2 years and 85.1% (1197/1407) at 5 years follow-up (Figure 1). The mean age of the participants was 24.5 ± 7.1 years and 74.3% were male. BPTB autograft reconstruction was performed in 1145 (81%) and HT autograft reconstruction was used for 262 (19%) patients. The majority of the participants were involved in Gaelic Football (41%), followed by Soccer (17%), Hurling (15%) and Rugby (11%). The main causes of injury were non-contact events (64.6%). The mean preoperative Marx score was 11.1 ± 5.1 points and the mean preoperative ACL-RSI score was 49.3 ± 26.1 points.

Prevalence, severity and location of pain

The pain questionnaire was completed at 6 months by 69.4% (976/1407), at 1 year by 73.9% (1040/1407), at 2 years by 94.4% (1328/1407) and at 5 years by 85.1%

TABLE 1 Baseline patient demographics and preoperative data.

Patient demographics	No. (%) or mean ± SD (range)
Primary ACL reconstruction	1407
Sex (male:female)	1046:361
Age (mean)	24.5 ± 7.1 (13–45)
Injured side (Right:Left)	788:619
Sports played at the time of injury	
Gaelic football	576 (41)
Soccer	246 (17)
Hurling	218 (15)
Rugby	153 (11)
Snow sports	68 (5)
Basketball	26 (2)
Other	120 (9)
Mechanism of primary injury	
Noncontact	919 (65)
Direct contact	271 (19)
Indirect contact	217 (15)
Preoperative Marx score	11.1 ± 5.1 (0–16)
Preoperative ACL-RSI score	49.3 ± 26.1 (0–100)
Graft type	
BPTB	1145 (81)
HT	262 (19)
Medial meniscal injury	
Nil	1059 (75)
Left in situ	178 (13)
Meniscectomy	101 (7)
Repair	69 (5)
Lateral meniscal injury	
Nil	855 (61)
Left in situ	233 (17)
Meniscectomy	279 (20)
Repair	40 (3)
Chondral pathology MFC	
Nil	1166 (84)
Grade 1–2	168 (12)
Grade 3–4	73 (5)
Chondral pathology LFC	
Nil	1185 (84)
Grade 1–2	201 (14)
Grade 3–4	21 (1)

TABLE 1 (Continued)

Patient demographics	No. (%) or mean ± SD (range)
Chondral pathology MTP	
Nil	1395 (99)
Grade 1–2	7 (<1)
Grade 3–4	5 (<1)
Chondral pathology LTP	
Nil	1395 (99)
Grade 1–2	9 (<1)
Grade 3–4	3 (<1)
Chondral pathology patella	
Nil	1374 (98)
Grade 1–2	29 (1)
Grade 3–4	4 (<1)
Chondral pathology trochlea	
Nil	1392 (99)
Grade 1–2	10 (<1)
Grade 3–4	5 (<1)

Abbreviations: ACLR, anterior cruciate ligament reconstruction; BPTB, bone–patellar tendon–bone; HT, hamstring tendon; LFC, lateral femoral condyle; LTP, lateral tibial plateau; MFC, medial femoral condyle; MTP, medial tibial plateau; SD, standard deviation.

(1197/1407). At 6 months postoperatively, the proportion of patients who responded 'Yes' to the presence of knee pain was significantly higher in the BTPB group compared to the HT group (40% vs. 25%, $p < 0.001$) (Table 2). There was also a significant difference in the distribution of pain with 26% of patients in the BPTB group reporting anterior knee pain compared to 6% of the HT group ($p < 0.001$). At the same time, 5% of patients in the HT group reported posterior knee pain compared to 2% of the BPTB group. Most pain in both groups was mild (BPTB: 25% vs. HT: 19%). The overall mean pain score was equivalent for both graft types (BPTB: 3.4/10 vs. HT: 3.3/10, $p = 0.768$). Severe pain was reported by 1.8% ($n = 14$) and 1.6% ($n = 3$) of patients in the BPTB and HT groups, respectively (Figure 2a).

At 1 year of follow-up, the prevalence of pain was similar between graft types (BPTB: 42% vs. HT: 39%, $p = 0.288$). There was also no significant difference in the location or severity of pain reported (Table 2A, Figure 2b). Similarly, at 2 years, there was no significant difference between grafts in terms of overall knee pain (BPTB: 34% vs. HT: 33%, $p = 0.830$) or the presence of anterior knee pain (BPTB: 19% vs. HT: 19%, $p = 0.702$). Furthermore, patient-reported pain severity was similar, with overall mean pain scores of 1.2 ± 2.0 for BPTB grafts and 1.3 ± 2.1 for HT autografts ($p = 0.99$) (Figure 2c). Severe pain was reported in 2.5% of BPTB patients and 2.0% of patients who underwent HT reconstruction at 2 years follow-up.

At 5 years follow-up, the overall prevalence of knee pain was lowest for both grafts, although patients in the BPTB group were more likely to report the presence of overall knee pain (BPTB: 31% vs. HT: 24%, $p < 0.032$) and anterior knee pain (BPTB: 16% vs. HT: 11%, $p < 0.027$) (Table 2B, Figure 2d). Notably, mild pain was the most commonly reported in the BPTB group, affecting 17.1% ($n = 166$) of patients. Moderate pain was reported by 12.2% ($n = 119$), while severe pain was experienced by 1.9% ($n = 18$). In the HT group, 14.2% of patients reported mild pain, 8.4% reported moderate pain, and 1% experienced severe pain. The overall mean severity scores at 5 years were 1.1 ± 1.9 for BPTB grafts and 0.8 ± 1.6 for HT grafts ($p < 0.020$) (Figure 2d).

Activity levels and knee function

There was no significant difference in IKDC scores between patients who received a BPTB vs. HT graft at 6 months postoperatively (74.6 ± 11.5 vs. 75.6 ± 12.4, $p = 0.168$). By 1 year and 2 years postoperatively, the IKDC scores were higher for the HT group (Table 3). However, the differences had small effect sizes (0.16 at 1 year and 0.15 at 2 years) and did not exceed the standard error of measurement (3.6–5.6 points) [9, 22]. At 5 years postoperatively, there was again no significant difference in IKDC score between the BPTB and HT grafts (86.8 ± 10.3 vs. 87.1 ± 11.5, $p = 0.16$).

Marx scores were comparable between graft types across all time points, with no statistically significant differences observed at the preoperative or any postoperative intervals, including 5 years post-surgery (BPTB: 8.9 ± 5.4 vs. HT: 8.7 ± 5.6, $p = 0.700$) (Table 3). Patients with chondral pathology also had significantly lower Marx scores at 5 years compared to those with no chondral pathology (Nil: 9.1 ± 5.4 vs. Grade 1/2: 7.9 ± 5.8 vs. Grade 3/4: 7.5 ± 5.3, $p < 0.20$). Return to play levels were also comparable for both grafts at 2 years (83.1% vs. 82.9%, $p = 0.753$) and 5 years (BPTB: 87.5% vs. 86.9%, $p = 0.812$).

KOOS/WOMAC scores at 5 years

The KOOS scores for patients five years post-ACL reconstruction showed no statistically significant differences between the BPTB and HT graft groups across all subscales (Table 4). Importantly, the mean KOOS Pain scores were equivalent in both groups (BPTB: 95.3 ± 8.5 vs. 95.5 ± 8.6, $p = 0.310$), as were the

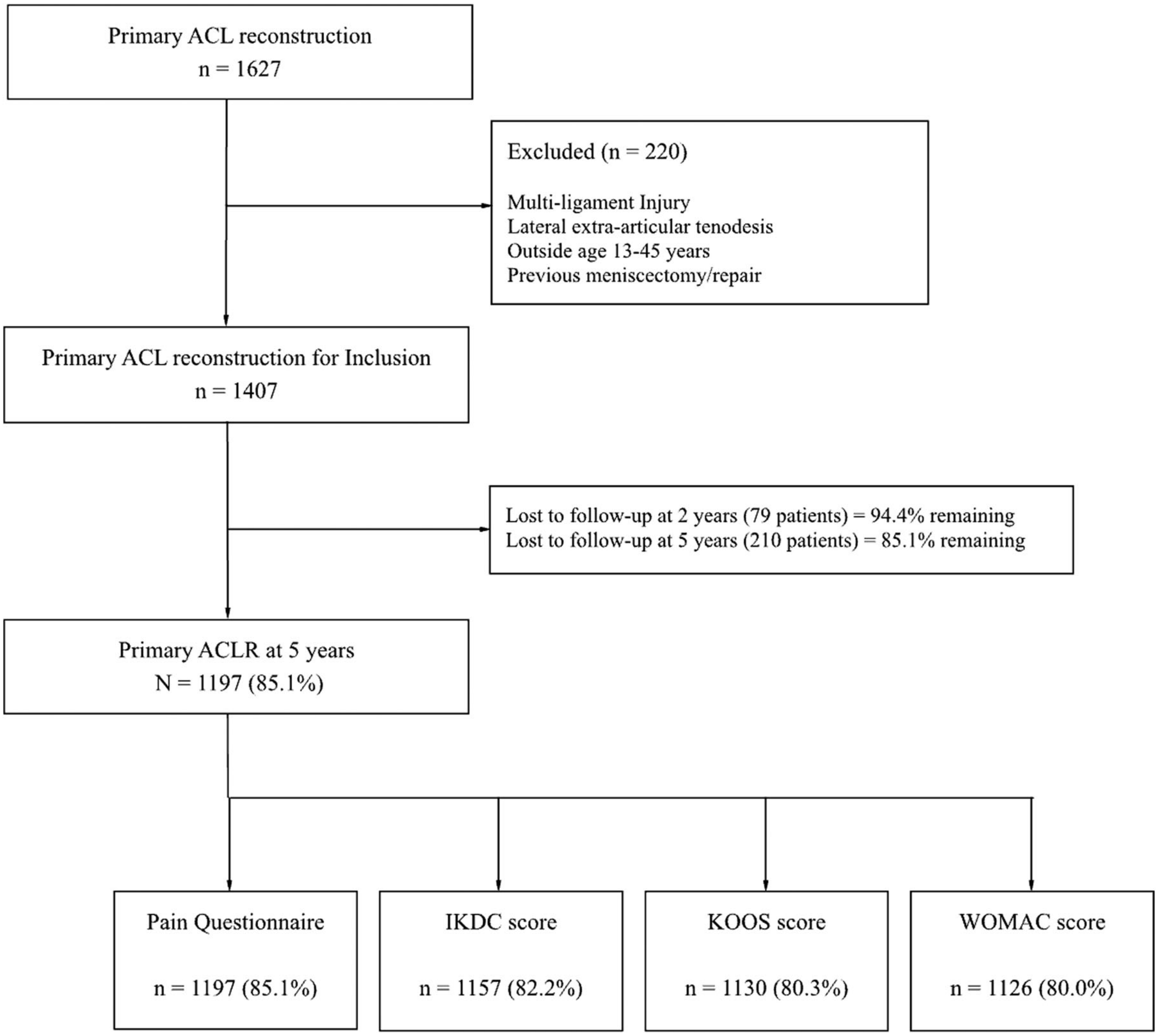

FIGURE 1 Flowchart of participant inclusion in the analysis. ACLR, anterior cruciate ligament reconstruction; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

mean KOOS Symptoms scores (90.8 ± 11.8 vs. 90.8 ± 12.6, $p = 0.508$). We observed that 2.7% (25/933) of patients in the BPTB group and 3.1% (6/197) of patients in the HT group scored ≤ 72 points on the KOOS pain subscale, meeting the threshold for consequential knee pain. Both groups also reported comparable scores for the activities of daily living, sports and quality of life subscales. WOMAC scores also demonstrated comparable outcomes between BPTB and HT for Pain, Stiffness, Function, and Total scores at 5 years follow-up (Table 4).

Factors associated with pain

At 6 months postoperatively, female patients were 1.41 times more likely to report the presence of pain compared to male patients (OR = 1.41, 95% CI = 1.02–1.95, $p < 0.035$). (Table 5). At all other postoperative time points, there was no statistically significant difference in the prevalence of pain between males and females. There was also a small association between the presence of pain and increasing age at 6 months (OR = 1.02, 95% CI = 1.01–1.04, $p < 0.014$) and 5 years postoperatively (OR = 1.06, 95% CI = 1.04–1.09, $p < 0.001$).

There was a higher likelihood that the presence of pain was reported by patients who received a BPTB autograft compared to a HT autograft at 6 months (OR = 1.78, 95% CI = 1.20–2.62, $p < 0.004$) and at 5 years (OR = 1.59, 95% CI = 1.05–2.41, $p < 0.027$) (Table 5). This association was not present at 1 year and 2 years follow-up. The presence of chondral pathology of the medial femoral condyle (MFC) was associated with increased odds of pain in the later years, particularly at 2 years (OR = 1.61, 95% CI = 1.07–2.41, $p < 0.022$) and 5 years (OR = 1.70, 95% CI = 1.09–2.67, $p < 0.020$). The effects of different

TABLE 2 (A, B): Location of knee pain for patients following BPTB and HT autograft ACL reconstruction at different time points during follow-up.

A	6 months			1 year		
	BPTB (*n* = 784)	**HT (*n* = 192)**	***p* value**	**BPTB (*n* = 838)**	**HT (*n* = 202)**	***p* value**
No pain	472 (60)	144 (75)	**<0.001**	480 (58)	124 (61)	0.288
Knee pain (yes)	312 (40)	48 (25)		358 (42)	78 (39)	
Location						
Anterior	205 (26)	12 (6)	**<0.001**	216 (26)	42 (21)	0.131
Posterior	16 (2)	9 (5)		13 (2)	8 (4)	
Medial	56 (7)	20 (10)		89 (11)	20 (10)	
Lateral	35 (4)	7 (4)		40 (5)	8 (4)	
B	**2 years**			**5 years**		
	BPTB (*n* = 1081)	**HT (*n* = 247)**	***p* value**	**BPTB (*n* = 972)**	**HT (*n* = 225)**	***p* value**
No pain	710 (66)	164 (66)	0.830	668 (69)	171 (76)	**0.032**
Knee pain (yes)	371 (34)	83 (33)		304 (31)	54 (24)	
Location						
Anterior	209 (19)	48 (19)	0.702	160 (16)	24 (11)	**0.027**
Posterior	18 (2)	7 (3)		14 (1)	2 (1)	
Medial	109 (10)	22 (9)		88 (9)	25 (11)	
Lateral	35 (3)	6 (2)		42 (4)	3 (1)	

Note: Expressed as No. (%). All statistically significant results are bold.

Abbreviations: ACL, anterior cruciate ligament; BPTB, bone–patellar tendon–bone; HT, hamstring tendon.

meniscus treatments and the presence of other chondral pathology showed variable significance without a consistent pattern over time (Table 5).

DISCUSSION

The most important finding of this study was that although patients who underwent ACLR with BPTB autografts were more likely to report AKP at 6 months, the pain was typically mild, improved with time, and did not impair activity levels or quality of life across the 5-year follow-up period. Factors such as female sex, older age and the presence of chondral pathology increased the likelihood of knee pain at various time points. Our findings demonstrate the importance of assessing pain comprehensively using multiple measures to distinguish between mild discomfort and clinically significant pain.

The results of our study align with previous research that demonstrates BPTB grafts are associated with increased AKP in the early post-operative period which gradually declines with time [38]. Rousseau et al. reported a similar trend, with the prevalence of AKP in patients with BPTB autografts decreasing from 16% within the first 2 years post-operatively to just 2.7% by the end of the second year [35]. Similarly, Webster et al. reported that although BPTB grafts were associated with a higher rate of AKP (52%) than HT grafts (17%) at the 2-year follow-up, this difference was no longer statistically significant at three and fifteen years post-operatively [11, 45]. This suggests that the biological healing processes and effective rehabilitation can resolve a substantial proportion of patient's symptoms. Therefore, clinicians should be specific when counselling patients about post-operative knee pain, describing the expected severity, emphasising that it improves with time and outlining strategies to mitigate it.

Most patients who underwent ACLR using a BPTB graft reported no pain and there was a similar prevalence of AKP for both grafts at 1 year and 2 years post-operatively. This suggests that BPTB graft use is not a primary causative factor for AKP, but a surrogate for associated, modifiable risk factors such as extensor mechanism dysfunction, saphenous nerve injury during dissection or the development of patellar tendonitis [24]. It is known that up to 40% of AKP may be attributed to tendinopathy arising during the early rehabilitation period [35]. Several studies have also demonstrated that AKP is associated with quadriceps weakness and extension deficits, irrespective of graft

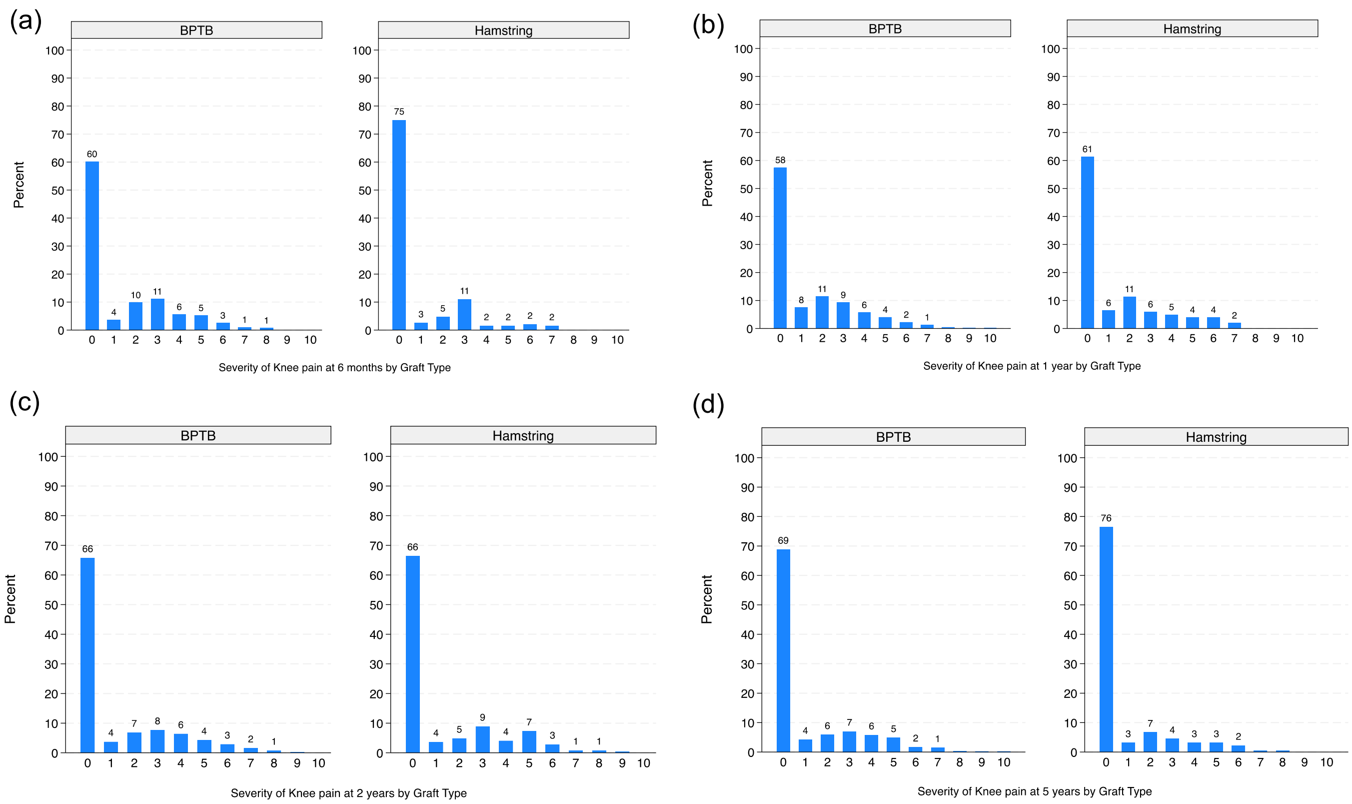

FIGURE 2 (a–d): Pain severity for patients following BPTB and HT autograft ACL reconstruction at different time points during follow-up. ACL, anterior cruciate ligament; BPTB, bone–patellar tendon–bone; HT, hamstring tendon.

TABLE 3 Patient activity levels and knee function reported as mean Marx and mean IKDC scores over 5 years by graft type.

Graft type	BPTB	Hamstring	*p* value
IKDC score			
6 mo.	74.6 ± 11.5 (42–96)	75.6 ± 12.4 (40–96)	0.168
1 year	82.9 ± 10.9 (36–96)	84.6 ± 11.0 (46–96)	**0.005**
2 years	86.4 ± 10.3 (26–96)	87.9 ± 9.6 (47–96)	**0.008**
5 years	86.8 ± 10.3 (22–96)	87.1 ± 11.5 (29–96)	0.016
Marx score			
Pre-op	11.2 ± 5.0 (0–16)	10.6 ± 5.4 (0–16)	0.295
6 mo.	8.0 ± 4.3 (0–16)	7.4 ± 4.4 (0–16)	0.091
1 year	10.6 ± 4.4 (0–16)	10.4 ± 4.7 (0–16)	0.883
2 years	9.8 ± 5.2 (0–16)	10.1 ± 5.2 (0–16)	0.406
5 years	8.9 ± 5.4 (0–16)	8.7 ± 5.6 (0–16)	0.700

Note: Expressed as mean ± SD, (range). All statistically significant results are bold.

Abbreviations: BPTB, bone–patellar tendon–bone; IKDC, International Knee Documentation Committee; SD, standard deviation.

TABLE 4 KOOS and WOMAC scores by graft type for patients 5 years following ACL reconstruction.

	BPTB	Hamstring	*p* value
KOOS score			
Pain	95.3 ± 8.5 (36–100)	95.5 ± 8.6 (47–100)	0.310
Symptoms	90.8 ± 11.8 (25–100)	90.8 ± 12.6 (32–100)	0.508
ADL	98.2 ± 6.2 (40–100)	98.1 ± 6.4 (53–100)	0.979
Sports	88.8 ± 15.8 (0–100)	89.8 ± 16.0 (5–100)	0.194
QOL	83.8 ± 19.4 (0–100)	84.7 ± 19.6 (19–100)	0.272
WOMAC score			
Pain	99.6 ± 1.4 (88–100)	99.5 ± 1.2 (92–100)	0.725
Stiffness	99.3 ± 1.2 (93–100)	99.5 ± 1.0 (95–100)	0.963
Function	98.8 ± 4.2 (59–100)	98.7 ± 4.4 (68–100)	0.640
Total	97.6 ± 6.4 (44–100)	97.7 ± 6.5 (59–100)	0.374

Note: Expressed as mean ± SD, (range).

Abbreviations: ACL, anterior cruciate ligament; BPTB, bone–patellar tendon–bone; KOOS, Knee Injury and Osteoarthritis Outcome Score; SD, standard deviation; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

type [13, 35, 42]. Injury to the infrapatellar branch of the saphenous nerve is another recognised source of AKP for both grafts, which has prompted technical refinements such as minimally invasive 'double window' harvesting for BPTB grafts and oblique incisions for HT grafts [16, 20]. For example, Calvert et al. reported that 77% of patients at 1 year and 54% of patients at 2 years following HT autograft reconstruction

TABLE 5 Multivariable logistic regression analysis of factors associated with the presence of knee pain at different time points following ACLR.

	6 months		1 year		2 years		5 years	
	OR	***p* value**	**OR**	***p* value**	**OR**	***p* value**	**OR**	***p* value**
Sex								
Female	**1.41 (1.02–1.95)**	**0.035**	1.18 (0.86–1.61)	0.312	1.19 (0.89–1.58)	0.248	1.33 (0.96–1.84)	0.083
Male	Reference		Reference		Reference		Reference	
Age	**1.02 (1.01–1.04)**	**0.014**	1.00 (0.98–1.01)	0.887	0.99 (0.98–1.01)	0.919	**1.06 (1.04–1.09)**	**0.001**
Marx score at follow-up	1.00 (0.99–1.00)	0.360	1.00 (0.99–1.00)	0.228	1.00 (0.99–1.00)	0.156	1.00 (0.99–1.00)	0.244
ACL-RSI (pre-op)	0.99 (0.99–1.00)		1.00 (0.99–1.00)	0.907	0.99 (0.99–1.00)	0.777	0.99 (0.99–1.00)	0.061
Graft type								
BPTB	**1.78 (1.20–2.62)**	**0.004**	1.34 (0.94–1.92)	0.108	1.15 (0.81–1.62)	0.420	**1.59 (1.05–2.41)**	**0.027**
Hamstring	Reference		Reference		Reference		Reference	
Injury with contact								
Noncontact	1.39 (0.94–2.04)	0.092	1.03 (0.72–1.46)	0.875	0.81 (0.58–1.12)	0.206	0.89 (0.60–1.30)	0.539
Indirect	1.30 (0.79–2.11)	0.295	0.75 (0.47–1.2)	0.234	0.71 (0.46–1.1)	0.125	0.67 (0.40–1.12)	0.124
Direct	Reference		Reference		Reference		Reference	
Medial meniscus treatment								
Nil	Reference		Reference		Reference		Reference	
Left in situ	1.15 (0.75–1.75)	0.509	0.94 (0.63–1.41)	0.775	1.18 (0.81–1.71)	0.381	1.30 (0.86–1.97)	0.212
Meniscectomy	1.11 (0.59–2.05)	0.753	0.84 (0.46–1.56)	0.597	1.10 (0.64–1.89)	0.741	1.22 (0.69–2.17)	0.494
Repair	1.77 (0.88–3.56)	0.107	1.43 (0.74–2.74)	0.286	1.61 (0.89–2.92)	0.115	1.45 (0.74–2.85)	0.280
Lateral meniscus treatment								
Nil	Reference		Reference		Reference		Reference	
Left in situ	1.04 (0.70–1.54)	0.836	1.01 (0.69–1.46)	0.977	0.72 (0.50–1.04)	0.080	1.20 (0.81–1.78)	0.358
Meniscectomy	1.07 (0.74–1.57)	0.691	1.10 (0.76–1.59)	0.600	1.03 (0.74–1.45)	0.825	1.23 (0.85–1.80)	0.276
Repair	0.65 (0.25–1.7)	0.384	0.59 (0.24–1.5)	0.271	0.94 (0.42–2.13)	0.889	0.63 (0.22–1.78)	0.385
Chondral pathology MFC								
Nil	Reference		Reference		Reference		Reference	
Grade 1–2	1.2 (0.73–1.96)	0.461	**1.61 (1.02–2.56)**	**0.040**	**1.61 (1.07–2.41)**	**0.022**	**1.70 (1.09–2.67)**	**0.020**
Grade 3–4	1.4 (0.69–2.9)	0.343	0.81 (0.40–1.63)	0.554	0.82 (0.43–1.56)	0.552	1.35 (0.70–2.61)	0.373

(Continues)

TABLE 5 (Continued)

	6 months		1 year		2 years		5 years	
	OR	*p* value	OR	*p* value	OR	*p* value	OR	*p* value
Chondral pathology LFC								
Nil	Reference		Reference		Reference		Reference	
Grade 1–2	1.37 (0.87–2.14)	0.171	**1.67 (1.12–2.50)**	**0.013**	1.21 (0.82–1.76)	0.320	1.47 (0.96–2.25)	0.073
Grade 3–4	1.18 (0.38–3.69)	0.771	0.78 (0.23–2.71)	0.701	1.25 (0.45–3.45)	0.664	0.49 (0.12–1.92)	0.309

Note: Expressed as OR (95% confidence interval, level of statistical significance). All statistically significant results are bold.

Abbreviations: ACLR, anterior cruciate ligament reconstruction; BPTB, bone–patellar tendon–bone; LFC, lateral femoral condyle; MFC, medial femoral condyle; OR, odd ratio; RSI, Return to Sport after Injury.

experienced issues with kneeling [6]. We believe that BPTB grafts should not be considered a sole determinant of AKP and that surgeons should consider the relative importance of surgical technique, rehabilitation quality and patient-specific factors.

Our findings contribute to the expanding body of recent evidence indicating comparable symptomatic outcomes between BPTB and HT grafts [18, 27, 36]. This may be due to contemporary graft-harvesting techniques and accelerated rehabilitation protocols. In our study, BPTB grafts were harvested through a minimally-invasive, mobile window over the distal portion of the patellar tendon. The patellar defect was grafted and the paratenon was individually dissected and meticulously closed with interrupted sutures avoid patellar baja. A systematic review by Lameire et al. indicated that bone grafting of BPTB harvest sites may reduce the incidence of AKP. However, substantial heterogeneity in outcome definitions, follow-up duration, and assessment tools across included studies significantly limits the interpretability this finding [23]. Similarly, while the paratenon contributes vascularity to the patellar tendon, evidence regarding the clinical benefit of its closure is limited. A systematic review of four randomised trials including 221 patients concluded that there was no clear evidence to suggest that closing the patellar tendon defect or paratenon significantly reduces donor-site morbidity compared to leaving it open [12]. Notably, even without suturing, the tendon gap tends to fill in with scar tissue over time without an increase in complications.

At 5 years follow-up, while patients in the BPTB group were 1.59 times more likely to have pain, most patients reported mild pain which did not translate into significant differences in KOOS pain (95.3 vs. 95.5) or KOOS symptom (90.8 vs. 90.8) scores. There was also no difference in the other KOOS subscales, the WOMAC score (97.6 vs. 97.7), the proportion of patients who met the criteria for consequential knee pain (BPTB: 2.7% vs. HT: 3.1%), the IKDC score (86.8 vs. 87.1), the Marx score (8.9 vs. 8.7) or return to play rates (87.5% vs. 86.9%). This highlights the importance of precise assessment and the use of multiple measures to obtain a comprehensive, nuanced understanding of postoperative knee pain. These outcomes align with the results of a systematic review by Samuelsson et al. who demonstrated that despite anterior knee pain being more prevalent with BPTB grafts, long-term follow-up showed no differences in activity levels between BPTB and HT grafts [37]. Similarly, a randomised trial by Feller et al. observed no difference in sports activity between BPTB and HT grafts or between those who reported anterior knee pain and those who did not at 2 years follow-up [11]. In the same trial, pain scores were similar for both grafts (BPTB: 3/10 vs. HT: 2.3/10) at 15 years follow-up [45]. Pinczewski et al. also found a higher prevalence of donor-site symptoms associated with BPTB grafts compared to HT autografts at 5 years (41% vs. 12%), though no patient-reported symptoms exceeded a mild severity [31]. A qualitative study by Sanjevic et al. reinforced that while mild AKP may persist after ACLR, patients did not find it bothersome and reported no impact on daily function or quality of life [39]. We believe that mild, non-limiting AKP should not deter surgeons from using BPTB autografts, especially given the significantly lower re-rupture rates compared to HT autografts in younger and level 1 athletes [26].

Our study suggests that female patients and older age at the time of surgery were associated with higher odds of pain at 6 months. Other notable factors associated with the presence of pain at longer-term follow-ups included the presence of medial femoral condyle chondral injuries and older age. Female sex has been previously associated with pain after ACLR and it is a well-recognised risk factor for anterior knee pain in general [4]. Female patients typically have a wider pelvis and larger Q-angle at the knee which alters patellar tracking [41]. This may be exacerbated during early ACL rehabilitation when the quadriceps are weak. Additionally, female patients demonstrate different movement patterns such as a tendency toward knee valgus collapse and internal rotation of the femur and quadriceps dominant knee loading during landing [29]. Sex-related differences have also been observed in psychological responses to both injury and the rehabilitation process [43, 47]. Chondral injuries have also previously been identified to affect pain outcomes negatively [7]. It is also possible that the association between older age and pain at 5 years is due to a surrogate marker of patellofemoral osteoarthritis. Jarvela et al. found that in a cohort of 100 ACLR patients with BPTB grafts, signs of patellofemoral osteoarthritis were seen in 47% of patients at 7 years follow-up [21]. There is inconsistent evidence regarding the influence of graft selection on the development of osteoarthritis, highlighting a need for further research in this area.

This study had several limitations. First, although it provides a prospective, longitudinal analysis of pain, it relies on quantitative data, which does not fully capture the complexity of pain experiences. Qualitative data would provide more personal insights into the impact of pain on patients' lives. There were also several different rehabilitation programmes undertaken given the geographical distribution of patients. This is an important consideration given the role of effective rehab in reducing knee pain. Future research should address these gaps to enhance our understanding of postoperative pain in patients who undergo ACL reconstruction.

CONCLUSION

Although BPTB grafts were associated with a higher prevalence of early AKP, this reduced gradually with time. Furthermore, most patients had mild pain which did not substantially impact knee function, activity levels, sports participation or quality of life. We recommend that future research employ standardised, multidimensional pain definitions and report both subjective and objective measures, enabling clinicians and patients to more accurately interpret postoperative pain. Our findings also support a more nuanced approach to pre-operative counselling, highlighting that graft choice is just one of many factors influencing postoperative pain. Equal attention should be given to rehabilitation quality, surgical technique, and individual patient characteristics in guiding expectations. We suggest that mild AKP should not deter surgeons from using BPTB autografts for ACLR given the other given the other advantages of this graft choice.

AUTHOR CONTRIBUTIONS

Timothy McAleese: Conceptualisation; methodology; data curation; formal analysis; visualisation; writing–original draft; writing–review and editing. **Niamh Keane**: Investigation; data curation; writing–review and editing. **Kate Sheridan**: Investigation; writing–review and editing. **Enda King**: Methodology; resources; supervision; writing–review and editing. **Kieran Moran**: Methodology; formal analysis; visualisation; writing–review and editing. **Mark Jackson**: Resources; project administration; writing–review and editing. **Daniel Withers**: Investigation; writing–review and editing. **Ray Moran**: Resources; supervision; writing–review and editing. **Brian M. Devitt**: Conceptualisation; supervision; project administration; writing–review and editing; final approval of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Approval received from the institutional review board of UPMC Sports Surgery Clinic. All patients provided informed consent to be involved with this research before enroling. All data is presented anonymously and de-identified.

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