Knee Surg Sports Traumatol Arthrosc
DOI 10.1007/s00167-015-3510-2

KNEE

Quantitative assessment of patellar vascularity following bone-patellar tendon-bone autograft harvest for ACL reconstruction

Kristofer J. Jones · Lionel E. Lazaro · Samuel A. Taylor · Nadine C. Pardee · Jonathan P. Dyke · Jo A. Hannafin · Russell F. Warren · Dean G. Lorich

Received: 3 May 2014 / Accepted: 12 January 2015

Abstract
Purpose Recent anatomic studies have suggested that the dominant arterial supply of the patella enters through the inferior pole. Based upon these findings, we hypothesized that bone-patellar tendon-bone graft harvest can significantly diminish patellar vascularity.
Methods Nine matched pair cadaveric knee specimens (mean age 47.4 years) were dissected and cannulated. A single knee was selected to undergo routine graft harvest, and the contralateral knee was left intact to serve as a control. Gadolinium was injected, and magnetic resonance imaging (MRI) signal enhancement was quantified to determine differences in uptake. Each matched pair was subsequently injected with a urethane polymer compound and dissected to correlate vessel disruption with MRI findings.
Results We identified two predominating patterns of vessel entry. In one pattern, the vessel entered the inferomedial aspect (five o'clock/right, seven o'clock/left) of the patella and was disrupted by graft harvest in 2/9 (22.2 %) pairs. In the second pattern, the vessel entered further medial (four o'clock/right, eight o'clock/left) and was not disrupted (7/9, 78.8 %). The mean decrease in gadolinium uptake following disruption of the predominant vessel measured 56.2 % (range 42.6–69.5 %) compared to an average decrease of 18.3 % (range 7.1–29.1 %) when the dominant arterial supply to the inferior pole remained intact ($p < 0.04$).
Conclusion Medial entry of the predominant vessel precluded vessel disruption. Disruption of the dominant arterial supply can result in a significant decrease in patellar vascularity. Modification of graft harvest techniques and areas of surgical dissection should be explored to minimize vascular insult. Further correlation with clinical studies/outcomes is necessary to determine a potential association between vascular insult and anterior knee pain.

K. J. Jones (✉)
David Geffen School of Medicine, University of California, Los Angeles, 10833 Le Conte Ave, 76-143 CHS, Los Angeles, CA 90095, USA
e-mail: kjjonesmd@gmail.com

L. E. Lazaro · S. A. Taylor · N. C. Pardee · J. A. Hannafin · R. F. Warren · D. G. Lorich
Hospital for Special Surgery, 535 E. 70th St, New York, NY 10021, USA

J. P. Dyke
Citigroup Biomedical Imaging Center, Weill Medical College of Cornell University, 516 E. 72nd St, New York, NY 10021, USA

Keywords ACL reconstruction · Patella vascularity · Bone-patellar tendon-bone autograft · Anterior cruciate ligament

Introduction

ACL graft selection is a widely debated topic that is influenced by several factors including patient preference, reported failure rates, associated costs, and donor site morbidity [8–10]. A recent study by Inacio et al. [16] investigated the association between various patient, surgeon, and hospital-based characteristics and ACL graft selection. The authors observed a significant association between patient gender, age, fellowship training status, average surgical volume, and hospital volume and graft choice. Clearly, graft selection is influenced by several factors.

While alternative graft choices are gaining popularity, bone-patellar tendon-bone (BPTB) autograft remains a widely utilized graft source for ACL reconstruction [14, 16, 20, 28, 34] and the preferred autogenous graft for primary

Published online: 22 January 2015

ACL reconstruction in the USA [29] Originally described by Jones in 1963 as a viable graft source for ACL reconstruction, BPTB autograft secured with interference screw fixation is largely favoured due to the excellent initial strength and the resultant bone-to-bone healing [6, 7, 19, 25, 40]. Several meta-analyses have also demonstrated greater improvements in postoperative knee stability, lower rates of graft failure, higher postoperative activity levels, and increased patient satisfaction compared to hamstring autografts, another prevalent graft source [3, 11, 12, 42]. Despite these promising results, the postoperative donor site morbidity associated with BPTB harvest remains a genuine concern. While the incidence of patellar fracture and patellar tendon disruption remains relatively low, the rate of anterior knee pain has been reported in up to 55 % of patients in a single series [23]. The relationship between anterior knee pain and postoperative extension deficit, shortening of the patellar tendon, injury to the infrapatellar nerve, and the development of a cyclops lesion has been proposed, but the precise cause of postoperative knee pain remains unclear [17, 18, 21, 22, 31, 39].

Iatrogenic disruption of the patellar blood supply has been implicated as a cause of anterior knee pain following various surgical procedures involving the knee, including total knee arthroplasty (TKA) and open reduction and internal fixation (ORIF) of patellar fractures [13, 27, 33]. In a recent cadaveric study by Lazaro et al. [27], the authors demonstrated the largest arterial contribution to the patella entered via the inferior pole of the patella. To our knowledge, no study has investigated the effect of BPTB graft harvest on patellar vascularity. Based upon the aforementioned anatomic observations, we hypothesized that BPTB graft harvest can result in significant reduction in intraosseous blood flow to the patella in a cadaveric model. The purpose of this study was to utilize gadolinium-enhanced magnetic resonance imaging (MRI) to quantify the effect of graft harvest on patellar vascularity.

Materials and methods

Cadaveric specimens

Following approval by the institutional review board at our hospital, we obtained eighteen fresh-frozen cadaveric knees (nine matched pairs) for experimental investigation. Donor specimens were obtained from Anatomic Gift Registry (Hanover, Maryland). There were three males and six females with a median age of 57.0 years (range 28–61 years) and a median BMI of 22.0 (range 16.3–38.6). Any specimen with a history of lower extremity trauma, previous lower extremity surgery and/or known vascular disease was excluded from the study. The cause of death for each specimen included respiratory failure (2), colon cancer (3), drug overdose (1), and lymphoma (3).

Cadaveric dissection and vessel cannulation

All specimen dissections were performed within the cadaveric laboratory at our institution. For each cadaveric knee, three DLP model 30000 vessel cannulas (Medtronic, Minneapolis, MN) were secured within the superficial femoral artery (SFA), anterior tibial artery (ATA), and the posterior tibial artery (PTA) using 2-0 Vicryl sutures (Johnson and Johnson, New Brunswick, New Jersey). For each vessel, cannula insertion occurred at a consistent anatomic location to ensure complete fill of the anastomotic ring during gadolinium and latex injection. These positions were as follows:

1. Superficial femoral artery (SFA): proximal to the bifurcation of the supreme genicular artery (descending genicular artery)
2. Anterior tibial artery (ATA): distal to the bifurcation of the anterior tibial recurrent artery
3. Posterior tibial artery (PTA): distal to the bifurcation of the ATA, but proximal to the bifurcation of the peroneal artery

A single knee from each matched pair was randomly selected using a computer program with random allocation software to undergo BPTB graft harvest utilizing a 6 cm longitudinal incision from the superior pole of the patella to the most inferior aspect of the patella. Surgical dissection remained superficial to the periosteal layer of the patella, as this deep layer contains the dorsal penetrating network of vessels described by Scapinelli [36]. Following adequate exposure of the patella, a handheld sagittal saw was used to harvest a 10 × 20 mm bone block. Harvest was completed with a narrow osteotome, and the bone block was elevated from the patella with the patellar tendon left attached to the harvested plug. Routine patellar tendon harvest was not performed for the purposes of this study in order to prevent iatrogenic damage of the underlying vasculature and ensure adequate perfusion of the peripatellar ring. Ultimately, this cadaveric model represents a “best-case” scenario in which the effect of the bone block harvest is isolated to determine the precise effect on intraosseous patellar blood flow. For each specimen, the contralateral side was utilized as a control.

MRI acquisition

All MRI studies were performed using a 3.0 Tesla Excite HD GE MRI scanner (General Electric Healthcare, Milwaukee, WI) with a quadrature knee coil. High-resolution fat-suppressed three-dimensional gradient echo sequences were acquired with a 20 cm field of view, a 512 × 384 matrix size, and 2 mm slice thickness both before and following the administration of contrast solution. All images were reconstructed to a resolution of 0.4 mm × 0.4 mm × 1.0 mm and acquisition parameters included repetition and echo times of 18.6/5.3 ms with a 35° flip angle. Prior to administration, gadolinium-diethylenetriaminepenta-acetic acid (Gd-DTPA) (Magnevist; Bayer Healthcare Pharmaceuticals Inc., Wayne, New Jersey) was diluted with normal saline at a 3:1 ratio and a total volume of 16 ml was manually injected into the cannulated vessels (SFA, ATA, and PTA) followed by a larger volume of 45 ml. Two separate volume injections were performed because a prior study demonstrated that the overall vasculature is best visualized following the initial (lower volume) infusion and signal enhancement within the bone is best visualized following the second (higher volume) infusion [27]. In order to maintain consistency amongst contrast injections, a similar syringe size was used for all vessels and a single investigator (LEL) manually injected the contrast at a constant pressure. Conventional clinical MRI sequences including static fat-suppressed and unsuppressed post-contrast T1 weighted three-dimensional gradient echo images were acquired after each injection. The MRI protocol was the same for all specimens in both the control and experimental groups.

Injection of latex for gross dissection

Following MRI evaluation, a polyurethane rubber compound (PMC-780; Smooth-On, Easton, PA) mixed with blue dye was injected into all three vessels (SFA, ATA, and PTA) through the previously inserted cannulas. The compound was allowed to polymerize for a minimum of 24 h at room temperature. Each specimen was manually dissected by one of four investigators (KJJ, LEL, SAT, NCP) to examine the extraosseous vasculature and confirm successful perfusion of the anastomotic ring. The specific characteristics of the vascular anatomy were recorded and compared amongst specimens.

MRI data analysis

The methodology used for quantitative MRI analysis has been described and validated in previous studies [5, 15, 27, 30]. The fat-suppressed images were examined for quantitative analysis, as they provided better detail of the Gd-DTPA through elimination of the signal produced by the normal fatty marrow. Each MRI study was independently evaluated by two of the investigators (NCP and LEL) specifically trained to evaluate the peripatellar vessel system using gadolinium-enhanced MRI in accordance with previous descriptions [27]. An automated custom computer program, designed by one of the investigators (JD), based on IDL 6.4 (ExcelisInc, Boulder, Colorado) was used for volumetric analysis. The coronal plane images of the patella were utilized for quantitative analysis of differences in gadolinium uptake between the test and control specimens. For each coronal section obtained for the specimens that underwent BPTB harvest (experimental specimen), the Region of Interest (ROI) was manually defined to include the entire osseous area of the patella, excluding the site of bone block harvest. The ROI definition of the osseous area for each experimental specimen was used to compare the same osseous area on the corresponding matched control (control specimen). We quantified signal intensity in the patella before and after administration of the contrast solution. This produced a weighted average of signal intensities from both the pre-contrast and post-contrast images. Quantitative analysis of the contrast enhancement in the patella comparing pre-contrast and post-contrast images was performed. The signal intensity per voxel was noted for comparison, and the overall signal intensity of the non-enhancing articular cartilage was used as a baseline for normalization. In all cases, a single reading of signal enhancement was obtained for each coronal section on both the control and experimental sides after calculating the weighted average of signal intensity per voxel. This study was approved by the institutional review board (ID #12138) at the Hospital for Special Surgery.

Statistical analysis

A nonparametric version of the independent samples t test (Mann–Whitney U test) was utilized to compare ROI values between experimental specimens that demonstrated disruption of the dominant arterial supply entering via the inferior pole of the patella. Statistical significance was set at $p < 0.05$. A bivariate correlation analysis was also used to calculate the intraclass correlation coefficient for the ROI values, and the number of mid-patellar vessels that were disrupted during bone block harvest.

Results

Contrast-enhanced MRI quantification revealed a mean signal decrease of 31.1 % (range 7.1–69.5 %) overall in specimens that underwent BPTB graft harvest compared with matched controls.

Radial artery disruption correlated with decreased patellar perfusion. Evaluation of coronal sequences revealed that the dominant inferomedial artery recently described by Lazaro et al. [27] was present in each specimen. Further assessment identified two primary patterns of vessel entry for this dominant arterial supply: inferomedial (IM) or superomedial (SM). In the first pattern (IM), the vessel entered the inferomedial pole of the patella at the five (right knee) or seven o'clock (left knee) position. This pattern was present in two matched pairs (2/9, 22.2 %), and BPTB graft harvest resulted in complete disruption of the dominant artery in both cases. In the second pattern (SM), the predominant vessel entered the patella from a more superomedial position (four o'clock position for a right knee and the eight o'clock position for a left knee). A superomedial location of patellar penetration appeared to preclude vessel disruption during BPTB graft harvest, as the dominant vessel was not disrupted in these specimens (7/9, 77.8 %). The impact of vessel disruption was statistically significant. The decrease of gadolinium enhancement was 56.2 % (range 42.6–69.5 %) when the vessel was disrupted (IM) compared with only 18.3 % (range 7.1–29.1 %) when the dominant arterial remained intact (SM) ($p < 0.04$) (Fig. 1a–d).

Mid-patellar vessel disruption was also correlated with the overall decrease in signal enhancement between experimental and control specimens. Scapinelli originally identified the mid-patellar vessel system as a series of vessels that penetrate the bone through vascular foramina located on the middle third of the dorsal surface of the patella [36]. Along with the polar vessel system, this arterial network serves as a primary vascular supply for the patella. Utilizing the number of mid-patellar vessels observed in each control specimen as a baseline, the total number of vessels disrupted along the penetrating dorsal surface was quantified and found to correlate with a decrease in signal enhancement between the experimental and control sides. This finding approached statistical significance (NS). In order to ensure accurate MRI assessment and confirm reliability of mid-patellar vessel disruption, surgical dissection was performed to correlate MRI and gross anatomic findings. The overall intraclass correlation coefficient (ICC) measured 0.881 (95 % CI 0.471–0.973), thereby indicating a strong agreement between MRI and gross anatomic findings.

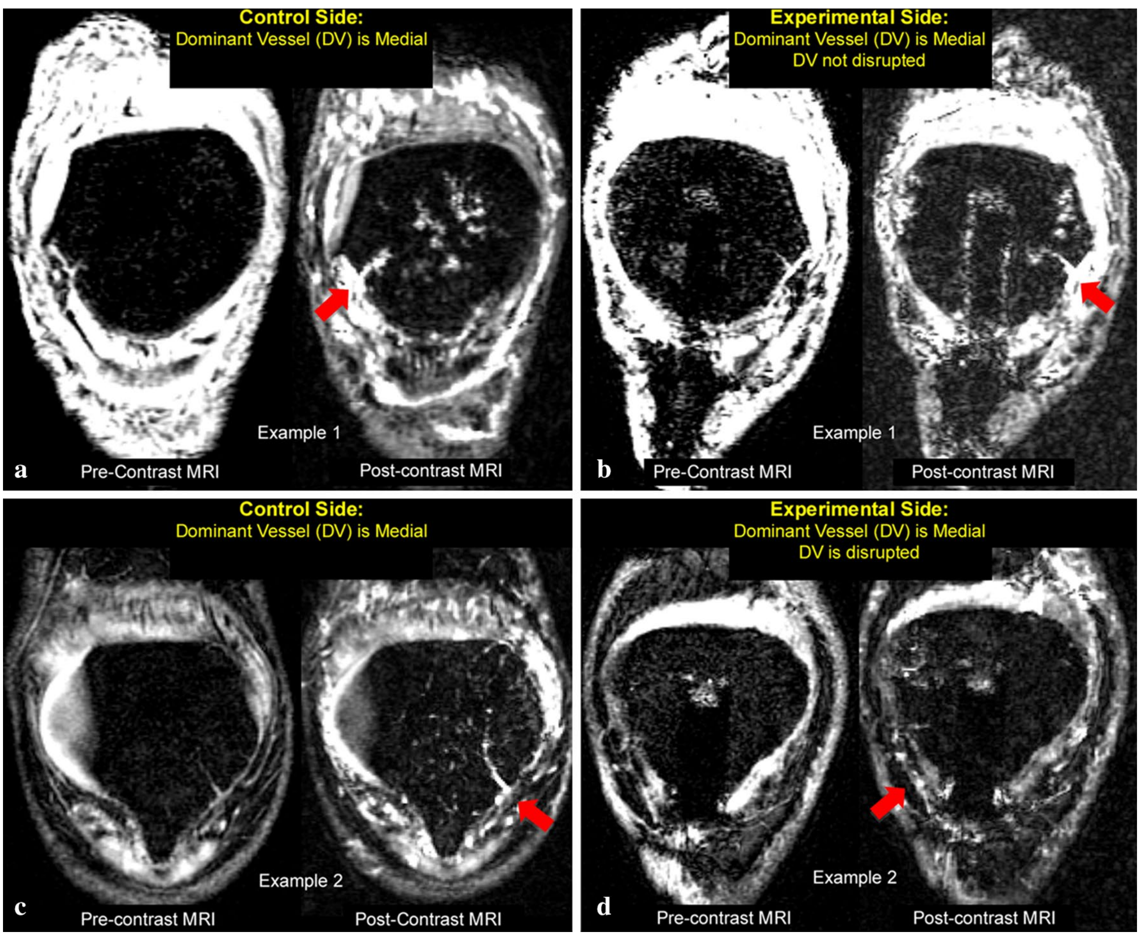

Fig. 1 **a–d** Matched pair MRI coronal sections (pre- and post-contrast) for the control and experimental groups. *Note*: The *red arrow* represents the dominant polar vessel entering the patella. **a**, **b** The dominant vessel enters near the four o'clock position and remains intact in the experimental specimen. **c**, **d** The dominant vessel enters closer to the five o'clock position and has been disrupted by the BPTB graft harvest in the experimental specimen

Discussion

The most important finding of the present study was that disruption of the predominant vessel during graft harvest resulted in a 56.2 % decrease in overall perfusion compared to only 18.3 % when the dominant arterial supply to the inferior pole remained intact ($p < 0.04$). Additionally, this study highlighted the variable vessel entry pattern into the inferomedial patella and its impact on patella vascularity in a cadaveric gadolinium-enhanced MRI model.

The ideal graft should be readily available and easily obtained, result in minimal donor site morbidity, exhibit biomechanical properties comparable to the native ACL, and facilitate secure fixation with rapid biologic incorporation. Patellar tendon autograft is a widely utilized graft source and largely favoured amongst orthopaedic surgeons in the USA despite various studies demonstrating an association between BPTB autograft harvest and anterior knee pain [1, 26, 29, 37]. The precise aetiology of symptomatic knee pain in the postoperative setting remains poorly understood; however, several mechanisms have been proposed. Some authors have developed novel harvesting techniques using two transverse incisions instead of a single longitudinal incision to limit potential morbidity associated with injury to the infrapatellar branches of the saphenous nerve [2, 41]. Inadequate rehabilitation with resultant quadriceps weakness and loss of knee extension has also been implicated as a potential cause of postoperative knee pain [32, 35, 38]. While this cadaveric study does not tie vascular insult to postoperative morbidity and anterior knee pain following ACL reconstruction, it does provide valuable data regarding the effect of graft harvest on the blood supply of the patella and provide a general framework for future clinical investigation.

Previous anatomic studies have defined the two dominant vessels systems (radial and dorsal) that originate from the peripatellar vascular ring to provide the intraosseous blood supply to the patella [4, 36]. The *dorsal system* includes the mid-patellar vessels that enter the anterior surface in an inferior to superior direction through vascular foramina located on the middle third of the patella. The *radial system* includes peripatellar vessels that penetrate the borders of the patella as well as the polar vessels that enter the inferior pole (Fig. 2a, b). The superior patella is largely supplied by the mid-patellar vessels, and this intrinsic arrangement predisposes the superior pole to osteonecrosis following vascular injury [4, 36]. A recent cadaveric study by Lazaro et al. [27] demonstrated the dominant arterial supply to the patella enters through the distal pole along the inferomedial border. Based upon these anatomic observations and the proximity of both the mid-patellar vessels and the dominant inferomedial vessel identified by Lazaro et al. [27], we hypothesized that BPTB graft harvest would result in a significant decrease in patellar vascularity. Overall, we demonstrated a mean signal decrease of 31 % following BPTB graft harvest in a cadaveric model. Interestingly, we found that superomedial vessel entry at the four (right knee) or eight (left knee) o'clock positions precluded injury to the dominant inferior vessel, thus resulting in greater preservation of gadolinium uptake. The mean decrease in gadolinium uptake measured 56 % following disruption of the dominant inferomedial vessel at the five

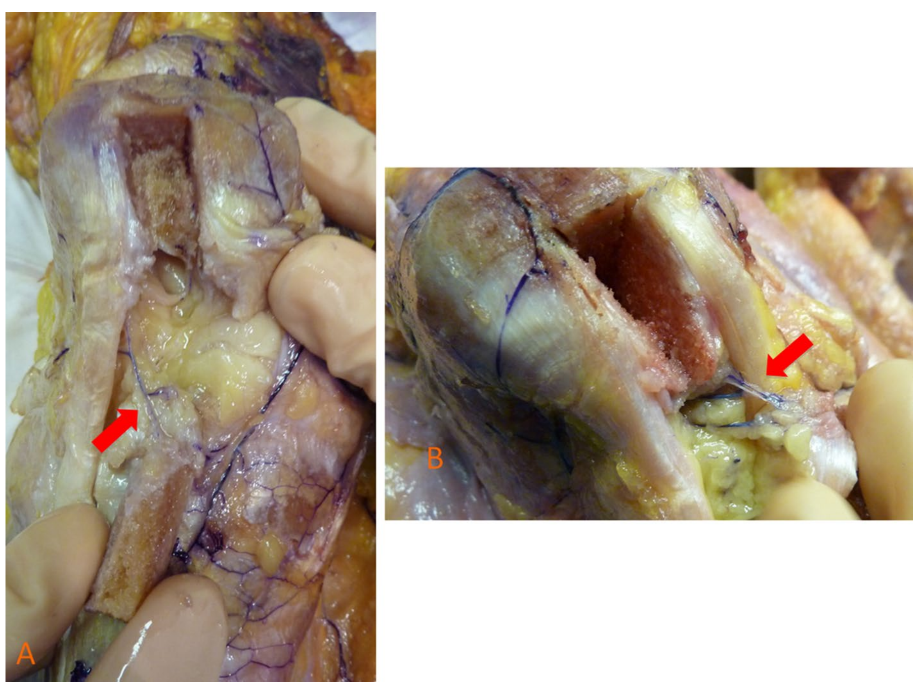

Fig. 2 **a**, **b** Following latex injection, gross anatomic dissection revealed the dominant polar vessel location in each specimen. **a** In this specimen, the *red arrow* demonstrates the course of the dominant polar vessel as it enters the harvested bone block (via the inferior pole). **b** In another specimen, the *red arrow* highlights the dominant polar vessel as it enter the inferior pole of the patella at the graft harvest site

(right knee) or seven (left knee) o'clock positions. Furthermore, increased disruption of mid-patellar vessels along the anterior surface was correlated with overall decrease in signal enhancement.

Several authors have investigated the potential association between surgical disruption of the patellar blood supply and symptomatic knee pain [13, 24]. Utilizing nuclear medicine bone scan, Gelfer et al. [13] found that both a standard medial parapatellar arthrotomy and the midvastus approach resulted in a relatively high incidence of vascular compromise that could be related to postoperative patellofemoral pain following TKA without patellar resurfacing. A similar study performed by Kohl utilized laser Doppler to determine the effect of medial parapatellar arthrotomy on intraoperative patellar blood flow [24]. The authors were unable to find a significant correlation between alterations in patellar vascularity and the diagnosis of anterior knee pain syndrome measured by the pain intensity numeric rating scale (NRS). They did note a significant correlation between knee flexion and diminished patellar blood flow, as intraoperative flow decreased to zero at flexion angles >100°. This may be an important observation when considering the transient effects of ACL reconstruction on patellar vascularity, as femoral tunnel preparation using anteromedial portal drilling is often performed with the knee hyperflexed.

This study represents a preliminary investigation of the effects of BPTB graft harvest on patellar blood flow, but further clinical studies are necessary to correlate these findings with postoperative morbidity. There are some obvious limitations to the study design that prevent us from making definitive conclusions. First, we utilized a human cadaveric model that fails to reproduce the physiologic response observed during ischaemic injury. Additionally, associated patellar tendon harvest was not performed in order to avoid iatrogenic damage to underlying vasculature and preserve adequate perfusion of the peripatellar ring. Overall, this model represents a "best-case" scenario in which only the intraosseous system is disrupted. It is possible that greater decreases in patellar blood flow could be observed with additional injury to the extraosseous vasculature. Despite these limitations, a previously published model of arterial investigation was used that has advantages for detailed assessment of vascular anatomy. This modality has been shown to accurately delineate both extraosseous and intraosseous vasculature and facilitate clear investigation of small vessel penetration into osseous regions that are difficult to quantify with manual dissection.

Overall, this cadaveric investigation provides insight into the effects of BPTB graft harvest on the patellar blood supply, and further clinical studies are necessary to determine a potential relationship between patellar devascularization and postoperative morbidity, including anterior knee pain. Given the detailed assessment of the vascular anatomy, this data can be used to establish modifications in graft harvest technique that can facilitate preservation of the dominant vessels as they enter the inferomedial patella.

Conclusion

The subject of anterior knee pain remains a diagnostic challenge following surgical procedures involving the knee, as various studies suggest many potential aetiologies. The results of this study demonstrate BPTB graft harvest can significantly affect patellar vascularity if the bone plug disrupts a substantial number of mid-patellar vessels and/or the dominant inferomedial penetrating vessel.

Acknowledgments The study was approved by the institutional review board at the Hospital for Special Surgery.

Conflict of interest The authors have no financial disclosures relevant to this study.

References

1. Barker JU, Drakos MC, Maak TG, Warren RF, Williams RJ, Allen AA (2010) Effect of graft selection on the incidence of postoperative infection in anterior cruciate ligament reconstruction. Am J Sports Med 38(2):281–286
2. Beaufils P, Gaudot F, Drain O, Boisrenoult P, Pujol N (2011) Mini-invasive technique for bone patellar tendon bone harvesting: its superiority in reducing anterior knee pain following ACL reconstruction. Curr Rev Musculoskelet Med 4:45–51
3. Biau DJ, Katcahian S, Kartus J, Harilainen A, Feller JA, Sajovic M, Ejerhed L, Zaffagnini S, Ropke M, Nizard R (2009) Patellar tendon versus hamstring tendon autografts for reconstructing the anterior cruciate ligament: a meta-analysis based on individual patient data. Am J Sports Med 37(12):2470–2478
4. Bjorkstrom S, Goldie IF (1980) A study of the arterial supply of the patella in the normal state, in chondromalacia patellae and in osteoarthrosis. Acta Orthop Scand 51(1):63–70
5. Boraiah S, Dyke JP, Hettrich C, Parker RJ, Miller A, Helfet D, Lorich D (2009) Assessment of vascularity of the femoral head using gadolinium (Gd-DTPA) enhanced magnetic resonance imaging: a cadaver study. J Bone Joint Surg Br 91(1):131–137
6. Brand J Jr, Weiler A, Caborn DN, Brown CH, Johnson DL (2000) Graft fixation in cruciate ligament reconstruction. Am J Sports Med 28(5):761–764
7. Brown CH, Hecker AT, Hipp JA, Myers ER, Hayes WC (1993) The biomechanics of interference screw fixation of patellar tendon anterior cruciate ligament grafts. Am J Sports Med 21(6):880–886
8. Cheung SC, Allen CR, Gallo RA, Ma CB, Feeley BT (2012) Patients' attitudes and factors in their selection of grafts for anterior cruciate ligament reconstruction. Knee 19(1):49–54
9. Cohen SB, Yucha DT, Ciccotti MC, Goldstein DT, Ciccotti MA, Ciccotti MG (2009) Factors affecting patient selection of graft type in anterior cruciate ligament reconstruction. Arthroscopy 25(9):1006–1010
10. Poehling GG, Curl WW, Lee CA, Ginn TA, Rushing JT, Naughton MJ, Holden MB, Martin DF, Smith BP (2005) Analysis

of outcomes of anterior cruciate ligament repair with 5-year follow-up: allograft versus autograft. Arthroscopy 21(7):774–785
11. Dunn WR, Lyman S, Lincoln AE, Amoroso PJ, Wickiewicz T, Marx RG (2004) The effect of anterior cruciate ligament reconstruction on the risk of knee reinjury. Am J Sports Med 32:1906–1914
12. Freedman KB, D'Amato MJ, Nedeff DD, Kaz A, Bach BR (2003) Arthroscopic anterior cruciate ligament reconstruction: a metaanalysis comparing patellar tendon and hamstring tendon autografts. Am J Sports Med 31:2–11
13. Gelfer Y, Pinkas L, Halperin N, Alk D, Robinson D (2003) Symptomatic transient patellar ischemia following total knee replacement as detected by scintigraphy: a prospective, randomized, double blind-study comparing the mid-vastus to the medial parapatellar approach. Knee 10:341–345
14. Granan LP, Inacio MC, Maletis GB, Funahashi TT, Engebretsen L (2012) Intraoperative findings and procedures in culturally and geographically different patient and surgeon populations: an anterior cruciate ligament reconsruction registry comparison between Norway and the USA. Acta Orthop 83(6):577–582
15. Hettrich CM, Boraiah S, Dyke JP, Neviaser A, Helfet DL, Lorich DG (2010) Quantitative assessment of the vascularity of the proximal part of the humerus. J Bone Joint Surg Am 92(4):943–948
16. Inacio M, Paxton EW, Maletis GB, Csintalan RP, Granan LP, Fithian DC, Funahashi TT (2012) Patient and surgeon characteristics associated with primary anterior cruciate ligament reconstruction graft selection. Am J Sports Med 40(2):339–345
17. Irrgang JJ, Harner CD (1995) Loss of motion following knee ligament reconstruction. Sports Med 19:150–159
18. Jackson DW, Schaefer RK (1990) Cyclops syndrome: loss of extension following intra-articular anterior cruciate ligament reconstruction. Arthroscopy 6:171–178
19. Jones KG (1963) Reconstruction of the anterior cruciate ligament: a technique using the central one-third of the patellar ligament. J Bone Joint Surg Am 45A(5):925–932
20. Kapoor B, Clement DJ, Kirkley A, Maffulli N (2004) Current practice in the management of anterior cruciate ligament injuries in the United Kingdom. Br J Sports Med 38:542–544
21. Kartus J, Magnusson L, Stener S, Brandsson S, Eriksson BI, Karlsson J (1999) Complications following arthroscopic anterior cruciate ligament reconstruction: a 2–5 year follow-up of 604 patients with special emphasis on anterior knee pain. Knee Surg Sports Traumatol Arthrosc 7:2–8
22. Kartus J, Stener S, Lindahl S, Engstrom B, Eriksson BI, Karlsson J (1997) Factors affecting donor-site morbidity after anterior cruciate ligament reconstruction using bone-patellar tendon-bone autografts. Knee Surg Sports Traumatol Arthrosc 5:222–228
23. Kleipool AE, van Loon T, Marti RK (1994) Pain after use of the central third of the patellar tendon for cruciate ligament reconstruction: 33 patients followed 2–3 years. Acta Orthop Scand 65(1):62–66
24. Kohl S, Evangelopoulos DS, Hartel M, Kohlhof H, Roeder C, Eggli S (2011) Anterior knee pain after total knee arthroplasty: does it correlate with patellar blood flow. Knee Surg Sports Traumatol Arthrosc 19:1453–1459
25. Kurosaka M, Yoshiya S, Andrish JT (1987) A biomechanical comparison of different surgical techniques of graft fixation in anterior cruciate ligament reconstruction. Am J Sports Med 15(3):225–229
26. Laxdal G, Kartus J, Hansson L, Heidvall M, Ejerhed L, Karlsson J (2005) A prospective randomized comparison of bone-patellar tendon-bone and hamstring grafts for anterior cruciate ligament reconstruction. Arthroscopy 21(1):34–42
27. Lazaro LE, Wellman DS, Klinger CE, Dyke JP, Pardee NC, Sculco PK, Berkes MB, Helfet DL, Lorich DG (2013) Quantitative and qualitative assessment of bone perfusion and arterial contributions in a patellar fracture model using gadolinium-enhanced magnetic resonance imaging: a cadaveric study. J Bone Joint Surg Am 95(19):1401–1407
28. Lyman S, Koulouvaris P, Sherman S, Do H, Mandl LA, Marx RG (2009) Epidemiology of anterior cruciate ligament reconstruction: trends, readmissions, and subsequent knee surgery. J Bone Joint Surg Am 91:2321–2328
29. Marx RG, Jones EC, Angel M, Wickiewicz TL, Warren RF (2003) Beliefs and attitudes of members of the America Academy of Orthopaedic Surgeons regarding the treatment of anterior cruciate ligament injury. Arthroscopy 19(7):762–770
30. Miller AN, Prasarn ML, Dyke JP, Helfet DL, Lorich DG (2011) Quantitative assessment of the vascularity of the talus with gadolinium-enhanced magnetic resonance imaging. J Bone Joint Surg Am 93(12):1116–1121
31. Muellner T, Kaltenbrunner W, Nikolic A, Mittlboeck M, Schabus R, Vecsei V (1998) Shortening of the patellar tendon after anterior cruciate ligament reconstruction. Arthroscopy 14(6):592–596
32. Niki Y, Hakozaki A, Iwamoto W, Kanagawa H, Matsumoto H, Toyama Y, Suda Y (2012) Factors affecting anterior knee pain following anatomic double-bundle anterior cruciate ligament reconstruction. Knee Surg Traumatol Arthrosc 20:1543–1549
33. Pakos E, Ntzani E, Trikalinos T (2005) Patellar resurfacing in total knee arthroplasty: a meta-analysis. J Bone Joint Surg Am 87:1438–1445
34. Rahr-Wagner L, Thillemann TM, Pedersen AB, Lind M (2014) Comparison of hamstring tendon and patellar tendon grafts in anterior cruciate ligament reconstruction in a nationwide population-based cohort study: results from the Danish registry of knee ligament reconstruction. Am J Sports Med 42(2):278–284
35. Sachs RA, Daniel DM, Stone ML, Garfein RF (1989) Patellofemoral problems after anterior cruciate ligament reconstruction. Am J Sports Med 17:760–765
36. Scapinelli R (1967) Blood supply of the human patella: its relation to ischaemic necrosis after fracture. J Bone Joint Surg Br 49(3):563–570
37. Shaieb MD, Kan DM, Chang SK, Marumoto JM, Richardson AB (2002) A prospective randomized comparison of patellar tendon versus semitendinosus and gracilis tendon autografts for anterior cruciate ligament reconstruction. Am J Sports Med 30(2):214–220
38. Shelbourne KD, Nitz P (1990) Accelerated rehabilitation after anterior cruciate ligament reconstruction. Am J Sports Med 18:292–299
39. Shelbourne KD, Trumper RV (1997) Preventing anterior knee pain after anterior cruciate ligament reconstruction. Am J Sports Med 25:41–47
40. Steiner ME, Hecker AT, Brown CH, Hayes WC (1994) Anterior cruciate ligament graft fixation: comparison of hamstring and patellar tendon grafts. Am J Sports Med 22(2):240–246
41. Tsuda E, Okamura Y, Ishibashi Y, Otsuka H, Toh S (2001) Techniques for reducing anterior knee symptoms after anterior cruciate ligament reconstruction using a bone-patellar tendon-bone autograft. Am J Sports Med 29(4):450–456
42. Yunes M, Richmond JC, Engels EA, Pinczewski LA (2001) Patellar versus hamstring tendons in anterior cruciate ligament reconstruction: a meta-analysis. Arthroscopy 17:248–257