Association of Smaller Intercondylar Notch Size With Graft Failure After Anterior Cruciate Ligament Reconstruction

Jonathan D. Hughes,*†‡ MD, PhD, Stephanie A. Boden,† MD, Rebekah Belayneh,† MD, Jenna Dvorsky,§ MS, Asher Mirvish,§ MS, Brian Godshaw,† MD, Mikael Sansone,‡ MD, PhD, Jon Karlsson,‡ MD, PhD, and Volker Musahl,†‡ MD

Investigation performed at the University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, USA

Background: Smaller intercondylar notch sizes have been consistently associated with a predisposition for primary anterior cruciate ligament tears.

Purpose: To evaluate the association between intercondylar notch size, graft size, and postoperative complications, including knee stiffness and return to the operating room, after primary anatomic anterior cruciate ligament reconstruction (ACLR).

Study Design: Case-control study; Level of evidence, 3.

Methods: This was a retrospective analysis of prospectively collected data from consecutive patients who underwent anatomic single-bundle primary ACLR using a bone-patellar tendon-bone or quadriceps tendon autograft performed by fellowship-trained orthopaedic sports medicine surgeons between April 2009 and August 2019. Graft failure was defined as patient report of instability, pathologic laxity on clinical examination, or graft rerupture confirmed by magnetic resonance imaging and/or subsequent arthroscopy. To ensure the purposeful selection of covariates, univariate analyses were conducted on the list of potential confounders selected a priori, and those with a significance value of $P < .10$ were considered for the multivariate regression model. Covariates found to be statistically significant with univariate analysis were patient age, notch size, and graft type. After validating all potential covariates, they were added to the regression model and then eliminated in a stepwise fashion.

Results: In total, 252 patients were included for analysis (99 bone-patellar tendon-bone and 153 quadriceps tendon autograft; age, 22.2 ± 7.0 years; graft size, 9.8 ± 1.0 mm; time to follow-up, 50.4 ± 28.9 months). Knee stiffness developed in 23 patients (9.1%), and 15 grafts failed (6.0%). Smaller notch size on magnetic resonance imaging was significantly associated with graft failure (P = .005). There was a significantly higher risk of graft failure with notch size <16 versus ≥16 mm (17.6% vs 2.3%; P = .005) with an odds ratio (OR) of 5.0 (95% CI, 1.7-15.1; P = .004). Notch size <15 mm was associated with the highest risk of graft failure (22.2%; OR, 5.8; 95% CI, 1.6-20.6; P = .006). There was no significant association between notch size or graft–notch size ratio and knee stiffness, meniscal injury, or cartilage damage at the time of ACLR, regardless of graft type.

Conclusion: Intercondylar notch size <16 mm was associated with a 5-fold increased risk of graft failure after primary anatomic ACLR.

Keywords: ACL; autograft; rerupture; bony morphology

Graft failure after anterior cruciate ligament (ACL) reconstruction (ACLR) is a well-documented complication that has been reported to occur in up to 14% of primary cases.[9,13,27] Despite newer, more anatomic techniques of reconstruction, complications including graft failure and symptomatic knee stiffness remain prevalent across the literature.[28] The femoral intercondylar notch varies in size and shape between individuals and is an important consideration among ACL surgeons.[16,25] While smaller notch sizes have consistently been associated with predisposition for primary ACL tears, the relationship between notch size and outcomes after ACLR has not been well elucidated. However, a prior study has suggested that geometric risk factors for primary ACL injury (including smaller

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intercondylar notch size) are similar to risk factors for ACL graft rupture after anatomic ACLR.[10,16,17,22]

Studies that have investigated notch size and outcomes after ACLR to date have not taken into account graft size in relation to notch size.[24] According to a study from the Swedish National Knee Ligament Registry, graft size is an important risk factor for graft failure, with a 0.86 times decreased risk of revision ACLR with every 0.5-mm increase in graft diameter up to 10.0 mm.[15] These are important considerations, as it is thought that a smaller intercondylar notch width in the setting of a relatively larger ACL graft may indicate a size mismatch that can predispose the ACL graft to injury with rotational or translational movements, thereby increasing the risk of symptomatic cyclops lesions and possibly even graft failure.[7,24]

The purpose of this study was to evaluate whether there is an association between intercondylar notch size and graft failure or postoperative knee stiffness after primary anatomic single-bundle ACLR. The secondary aim of the study was to evaluate if graft size in comparison with notch size (ie, graft-notch [G-N] ratio) had any association with graft failure and symptomatic knee stiffness. It was hypothesized that a smaller intercondylar notch size and a smaller G-N ratio of notch size to graft size would correlate with an increased risk of graft failure and symptomatic knee stiffness.

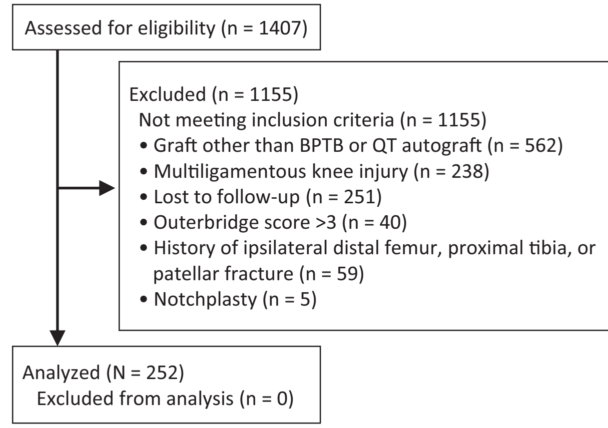

Figure 1. Flowchart of patient enrollment in the study. BTB, bone-patellar tendon-bone autograft; QT, quadriceps tendon autograft.

METHODS

After approval from the institutional review board was obtained, we retrospectively reviewed the records of all patients who underwent anatomic single-bundle primary ACLR by 5 fellowship-trained orthopaedic sports medicine surgeons (including J.D.H. and V.M.) at our institution between April 2009 and August 2019. Inclusion criteria consisted of skeletally mature patients undergoing primary single-bundle ACLR with either bone-patellar tendon-bone (BPTB) autograft or quadriceps tendon (QT) autograft, with preoperative magnetic resonance imaging (MRI) available for review. Skeletal maturity was determined by the presence of closed physes on knee radiographs. Exclusion criteria were revision ACLR, patients with a history of distal femoral, proximal tibial, or patellar fracture, patients with multiple ligament knee injuries, patients who underwent notchplasty, and patients with knee arthritis (Outerbridge grade >3) with associated osteophytes seen on plain radiographs, MRI, or arthroscopy. A total of 1407 patients were identified, of whom 252 patients met criteria for analysis (Figure 1).

Demographic data for each patient in the study were recorded including age, sex, and laterality. Each patient underwent an arthroscopic evaluation of the knee at the time of ACLR, and data from this evaluation were collected from operative notes including tourniquet time, graft size, use of bone block intraoperatively, meniscal pathology, performance of chondroplasty and/or notchplasty, femoral fixation, and tibial fixation types. Graft size was determined intraoperatively using a sizing device and recorded in the operative note by the operating surgeon. Clinical outcomes included graft failure, return to operating room for any reason, infection, and knee stiffness. Knee stiffness was defined as clinically significant loss of motion requiring return to the operating room for manipulation under anesthesia and/or lysis of adhesions. Graft failure was defined according to the criteria described previously as patient report of instability, pathologic laxity on clinical examination (Lachman 2B or greater), and/or an MRI or arthroscopic diagnosis of rupture or absence of the ACL graft.[20] G-N ratio was calculated by dividing intra-articular graft size by notch size.

*Address correspondence to Jonathan D. Hughes, MD, PhD, UPMC Freddie Fu Sports Medicine Center, 3200 South Water Street, Pittsburgh, PA 15203, USA (email: hughesjd3@upmc.edu).

†Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, UPMC Freddie Fu Sports Medicine Center, Pittsburgh, Pennsylvania, USA.

‡Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden.

§University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania, USA.

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Ethical approval for this study was obtained from the University of Pittsburgh (ref No. STUDY19030196).

Intercondylar Notch Measurements

Intercondylar notch measurement via MRI has been validated as a reliable method to predict intercondylar notch width on arthroscopy.[19] For MRI notch measurement, a preoperative MRI single axial T2 fluid sensitive sequence image was used where the entire notch entrance was visible. The ruler function built into the imaging software Philips iSite (Koninklijke) was selected. The notch base width was measured as the distance between the medial articular cartilage margin of the lateral femoral condyle and the lateral articular margin of the medial femoral condyle (Figure 1). The notch measurements for each patient were conducted by 2 authors: 1 orthopaedic surgery sports medicine fellow (S.A.B.) and 1 fellowship-trained orthopaedic sports medicine surgeon (J.D.H.). The authors were blinded to the outcome at the time of notch measurement. The height of the lateral and medial walls of the notch was then measured, and the mean height calculated (Figure 2). This resultant number was then divided by 3 to obtain the height increment at which one-third and two-thirds midnotch width measurements should be taken.[21] The means of these measurements were then calculated. The interrater reliability of the notch measurements, calculated using the intraclass correlation coefficient (ICC), was excellent (ICC = 0.99).

Surgical Treatment

All patients underwent anatomic single-bundle primary arthroscopic ACLR at our institution by 1 of the 5 fellowship-trained orthopaedic sports medicine surgeons, using either BPTB or QT autografts. Patients underwent surgery only after recovering active range of motion after their initial ACL injury with ≥0° of extension and 90° of flexion. For each patient, an examination under anesthesia was performed on the day of surgery, evaluating: anterior drawer, posterior drawer, Lachman test, pivot shift test, dial test, varus and valgus laxity at 0° and 30° of knee flexion. Diagnostic arthroscopy was used to confirm ACL rupture and diagnose associated pathology including meniscal tears and chondral injury. All patients were confirmed to have complete ACL tear on diagnostic arthroscopy. Meniscal repair was performed before ACLR, when indicated. Either QT or BPTB autografts were harvested via standard technique.[6,8] Most QT grafts were soft tissue, and the decision to use a bone block was made on intraoperative measurement of QT length. Anatomic femoral and tibial footprints were determined using remnant tissue of the native ACL as well as intra-articular landmarks.[3,4] Tunnel position was checked after drilling an initial pilot hole and then confirming appropriate placement before drilling and reaming. Tunnel size was matched to graft size. Femoral fixation consisted of suspensory, interference screw, or 4.5-mm bicortical screw post based on surgeon preference. Similarly, tibial fixation consisted of suspensory, interference screw, press-fit core bone block with suture disc, or screw post based on surgeon preference. After fixation, the graft was probed and a Lachman test was performed to ensure stability.

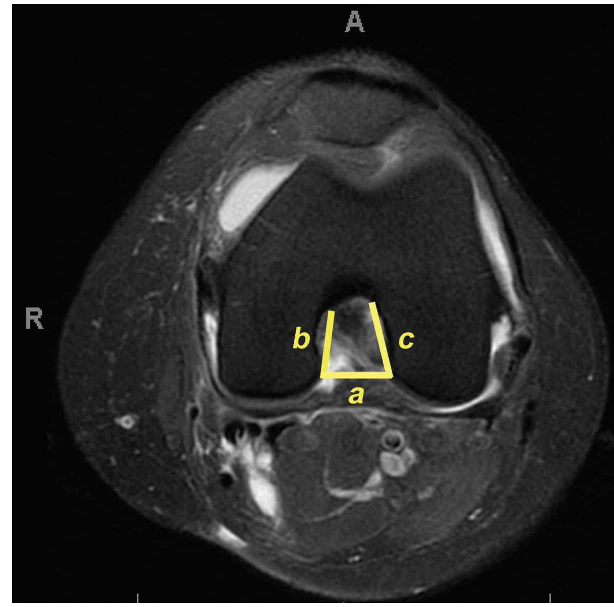

Figure 2. T2-weighted axial magnetic resonance imaging scan of a right knee showing *a* – the notch width at the base, *b* – the medial wall height, and *c* – the lateral wall height. After measuring the height of the lateral and medial walls of the notch, the mean height was calculated. This number was then divided by 3 to obtain the height increment at which one-third and two-thirds midnotch width measurements should be taken. Notch width was calculated at each interval and then averaged to obtain the mean notch width. A, anterior; r, right.

Postoperative Protocol

All patients were placed in a hinged knee brace postoperatively, which was locked in extension for ambulation. Patients without meniscal repair were allowed weightbearing as tolerated, and the brace was unlocked for ambulation after 1 week. Patients with meniscal repair were either toe touch weightbearing or weightbearing as tolerated depending on type and location of meniscal tear. Phase-adjusted supervised physical therapy was initiated after the initial postoperative visit at 1 to 2 weeks and continued for 6 to 9 months depending on the patient's progress and activity goals. After regaining strength and neuromuscular control with a quadriceps index of >85%, they initiated a functional progression to sprinting, cutting, and plyometric activities with an eventual transition to sport-specific training. Prior to clearance to return to sport, patients completed return-to-sports testing.

Statistical Analysis

Stata (Version 17; StataCorp) was used for statistical analysis. Data were reported as means and standard

TABLE 1
Patient and Operative Characteristics[a]

	All Patients (N = 252)	BPTB Autograft (n = 99)	QT Autograft (n = 153)	*P*
Age at surgery, y	22.2 ± 7.0 (13.7-52.4)	20.7 ± 4.2 (14.6-33.9)	23.2 ± 8.2 (13.6-52.4)	**.005**
Sex, male	165 (65.5)	76 (76.8)	89 (58.2)	**.003**
Laterality, right	126 (50.0)	43 (43.4)	83 (54.2)	.100
Graft size, mm	9.8 ± 1.0 (7.0-15.0)	9.9 ± 0.5 (7.0-11.0)	9.8 ± 1.2 (7.0-15.0)	.600
Notch size on MRI, mm	18.7 ± 2.5 (13.2-27.4)	17.5 ± 2.2 (13.5-23.8)	19.5 ± 2.4 (13.2-27.4	**<.001**
G-N ratio	0.5 ± 0.1 (0-0.8)	0.6 ± 0.1 (0.3-0.7)	0.5 ± 0.1 (0-0.8)	.100
Concomitant procedures				
Partial medial meniscectomy	17 (6.7)	6 (6.1)	11 (7.2)	.800
Medial meniscal repair	75 (29.8)	27 (27.3)	48 (31.4)	.640
Medial meniscus root repair	3 (1.2)	2 (2.0)	1 (0.7)	.066
Partial lateral meniscectomy	48 (19.0)	22 (22.2)	26 (17.0)	.342
Lateral meniscal repair	40 (15.9)	13 (13.1)	27 (17.6)	.400
Lateral meniscus root repair	13 (5.2)	4 (4.0)	9 (5.9)	.800
Chondroplasty	4 (1.6)	3 (3.0)	1 (0.7)	.650
Microfracture	1 (0.4)	0 (0.0)	1 (0.7)	≥.999
Return to operating room	54 (21.4)	26 (26.3)	28 (18.3)	.070
Knee stiffness	23 (9.1)	12 (12.1)	11 (7.2)	.190
Infection	1 (0.4)	0 (0.0)	1 (0.7)	≥.999
Graft failure	15 (6.0)	10 (10.1)	5 (3.3)	**.030**
Meniscal injury	22 (8.7)	9 (9.1)	13 (8.5)	≥.999
Time to follow-up, mo	50.4 ± 28.9 (11.0-146.3)	52.3 ± 30.3 (11.0-146.3)	49.9 ± 27.8 (11.1-128.7)	.700

[a]Data are shown as mean ± SD (range) or n (%). Boldface *P* values indicate statistically significant difference between groups ($P < .05$). BPTB, bone-patellar tendon-bone autograft; G-N, graft size to notch size ratio; MRI, magnetic resonance imaging; QT, quadriceps tendon autograft.

deviations. Chi-square tests were used for comparison of categorical variables, and the independent *t* test was used for comparison of continuous variables. Statistical significance was assumed for $P < .05$.

To ensure the purposeful selection of covariates, univariate analyses were conducted on the list of potential confounders selected a priori. Those with a significance value <.10 were considered for the multivariate regression model. Covariates found to be statistically significant with univariate analysis were patient age, notch size, and graft type. After validating all potential covariates, they were added to the regression model and then eliminated in a stepwise fashion. If the covariate was no longer significant with multivariate analysis, confounding was defined as a change in the parameter of interest by >20% compared with the previous model.

RESULTS

Results for BTB and QT Groups

Of the 252 patients, 99 patients underwent ACLR with a BPTB autograft and 153 with a QT autograft. The mean age of patients included in the study was 22.2 ± 7.0 years (range, 14-52 years). Mean time to final follow-up was 50.4 ± 28.9 months. At the time of surgery, younger patients were more likely to have a BPTB autograft (20.7 ± 4.2 vs 23.2 ± 8.2 years; $P = .005$). Patient demographics are summarized in Table 1. The mean graft size was 9.8 ± 1.0 mm, while the mean femoral notch size on MRI was 18.7 ± 2.5 mm. Overall, 23 patients developed knee stiffness (9.1%) and 15 grafts failed (6.0%). There was a significant difference in graft failure between the BPTB and QT groups (10.1% vs 3.3%; $P = .030$). There was no significant difference in rate of knee stiffness between BPTB and QT grafts (12.1% vs 7.2%; $P = .190$) (Table 1).

Predictors of Failure

Univariate predictors of graft failure were younger age and smaller notch size (Table 2). Among all patients who underwent ACLR, there was a significant association between smaller notch size on MRI and graft failure ($P = .005$), with notch size on average 1.3 ± 0.05 mm smaller in patients with graft failure. Specifically, patients with a mean intercondylar notch size on MRI of <16 mm had a significantly higher risk of graft failure (17.6%; $P = .004$) with an odds ratio (OR) of 5.0 (95% CI, 1.7-15.1) and the highest risk in those with mean intercondylar notch size on MRI of <15 mm (22.2%; OR = 5.8; 95% CI, 1.6-20.6; $P = .006$) (Table 3). In the multivariate analysis, only patient age was independently predictive of graft failure ($P = .030$) (Table 4).

Association of Notch Measurements With Graft Failure

The G-N ratio was not significantly different in patients with graft failure (mean 0.6 ± 0.1 vs 0.5 ± 0.1; $P = .100$). Overall, there was no significant association between

TABLE 2
Univariate Analysis of Factors Associated With Graft Failure[a]

Variable	Failure (n = 15)	No Failure (n = 237)	*P*
Age at surgery, y	18.4 ± 3.1 (13.6-25.2)	22.4 ± 7.2 (14.1-52.4)	**.043**
Sex, male	10 (66.7)	155 (65.4)	≥.999
Graft size, mm	9.9 ± 1.1 (7.0-12.0)	9.8 ± 1.0 (7.0-15.0)	.800
Notch size on MRI, mm	17.5 ± 2.5 (14.4-21.4)	18.8 ± 2.5 (13.2-27.4)	**.005**
Notch size ≥16 mm, n	9	212	
Notch size <16 mm, n	6	25	
G-N ratio	0.6 ± 0.1 (0.4-0.7)	0.5 ± 0.1 (0-0.8)	≥.999
Graft type			**.030**
BPTB autograft	10 (66.7)	89 (37.6)	
QT autograft	5 (33.3)	148 (62.4)	
Concomitant procedures			
Partial medial meniscectomy	0 (0.0)	17 (7.2)	.600
Medial meniscal repair	3 (20.0)	72 (30.4)	.600
Medial meniscus root repair	0 (0.0)	3 (1.3)	≥.999
Partial lateral meniscectomy	4 (26.7)	44 (18.6)	.500
Lateral meniscal repair	2 (13.3)	38 (16.0)	≥.999
Lateral meniscus root repair	0 (0.0)	13 (5.5)	≥.999
Chondroplasty	0 (0.0)	5 (2.1)	≥.999
Microfracture	0 (0.0)	1 (0.4)	≥.999

[a]Data are shown as mean ± SD (range) or n (%) unless otherwise indicated. Boldface *P* values indicate statistically significant difference between groups ($P < .05$). BPTB, bone-patellar tendon-bone autograft; G-N, graft size to notch size ratio; MRI, magnetic resonance imaging; QT, quadriceps tendon autograft.

TABLE 3
Graft Failure Risk According to Intercondylar Notch Size[a]

Notch Size on MRI, mm	Failure, n/N (%)	Odds Ratio (95% CI)	*P*
≥20	4/71 (5.6)	0.95 (0.29-3.1)	.930
<20	11/186 (5.9)	1.1 (0.32-3.4)	.930
<19	10/150 (6.7)	1.4 (0.49-4.4)	.490
<18	8/104 (7.7)	1.8 (0.62-5.1)	.280
<17	7/67 (10.4)	2.6 (0.90-7.5)	.080
<16	6/34 (17.6)	5.0 (1.7-15.1)	**.004**
<15	4/18 (22.2)	5.8 (1.6-20.6)	**.006**

[a]Boldface *P* value indicates statistical significance ($P < .05$). MRI, magnetic resonance imaging.

TABLE 4
Multivariate Predictors of Graft Failure[a]

Variable	Odds Ratio (95% CI)	*P*
Age at surgery	0.8 (0.6-1.0)	**.030**
Notch size on MRI	0.9 (0.7-1.1)	.300
Graft type	0.3 (0.1-1.1)	.090

[a]Boldface *P* value indicates statistical significance ($P < .05$). MRI, magnetic resonance imaging.

notch size, graft size, or G-N ratio and knee stiffness or infection. There was no significant association found between these variables and postoperative complications within the BPTB autograft and QT autograft groups.

DISCUSSION

In the present study, smaller intercondylar notch size as measured on MRI was significantly associated with rate of graft failure, with a mean 1.3-mm smaller notch width in patients with graft failure. Specifically, patients with a notch width of <16 mm measured on MRI were significantly more likely to have graft failure compared with those with notch size of ≥16 mm (17.6% vs 2.3%), and the highest graft failure rate was found in patients with intercondylar width <15 mm with a 22.2% graft failure rate and an OR of 5.8. While notch size was significantly associated with graft failure, this may be related to patient age, as only patient age was independently predictive of graft failure in the multivariate analysis. There was no significant association between notch size or graft–notch size ratio and knee stiffness, meniscal injury, or cartilage damage at the time of ACLR, regardless of the type of graft used.

The femoral intercondylar notch has been an anatomic site of interest with respect to ACL injury and reconstruction since the 1930s, when it was first postulated that a smaller notch width may place increased stress on the ACL during certain knee movements, thereby increasing the risk of ACL failure in patients with a narrow notch.[24] Since that time, numerous studies have identified smaller intercondylar notch size as a significant risk factor for initial ACL injury,[1,12] but the effect of notch size on outcomes after ACLR remains controversial with conflicting results.[24] To date, there is no universally accepted consensus regarding the relationship between intercondylar notch size and outcomes after ACLR. A previous study evaluating the effect of notch size and graft failure was limited by inadequate power, variable methods of measuring intercondylar notch size, and/or outdated techniques of ACLR including nonanatomic transtibial reconstruction.[24]

The results of the current study corroborate recent studies that have found narrow intercondylar notch width to be significantly predictive of graft failure after primary ACLR. A recent retrospective review of age- and sex-matched patients that underwent physeal-sparing ACLR found increased failure in patients with a smaller, narrower, and steeper intercondylar notch measured on MRI.[18] Prior studies of risk factors for primary ACL injury have suggested a cutoff value for intercondylar notch size of 17 mm for a significantly increased risk of ACL rupture; however, no such cutoff has been demonstrated for risk of graft failure after ACLR.[14] The current study found a similar cutoff for risk of graft failure after primary ACLR, with a 5.0-fold increased risk in patients with notch size <16 mm and a 5.8-fold increased risk in patients with notch size <15 mm.

While smaller mean notch size was noted in patients with symptomatic knee stiffness, this was not statistically significant in the study population. Notably, the current study was not adequately powered to detect a significant difference in knee stiffness rates, given the low number of patients who developed knee stiffness in the study population. A recent systematic review investigating the development of a symptomatic cyclops lesion after ACLR identified narrow intercondylar notch as a significant risk factor.[11] Similarly, a recent retrospective case-control study investigated the geometry of the intercondylar notch as measured on MRI and found that notch geometry was a risk factor for the development of cyclops lesions with or without ACL graft failure.[5] The risk of symptomatic cyclops lesion in patients with a narrow intercondylar notch has been suggested to occur due to graft impingement and may be more likely in patients with graft–notch size mismatch.[5,7,23] Previous studies have indicated that a smaller intercondylar notch may be correlated with a functionally oversized graft, increasing the risk for graft impingement.[23,24] This relationship was not demonstrated in the current study, although the results are likely limited by the relatively small sample size. Based on the findings of the current study, intercondylar notch size and graft size in relation to notch size were not associated with postoperative knee stiffness or graft failure after ACLR.

Limitations

The present study has limitations. It was retrospective in nature and was therefore inherently subjected to the limitations of retrospective studies including selection bias. Graft type was chosen based on surgeon and patient preference, introducing the possibility of selection bias. Arthroscopic management of remnant native ACL tissue was operator dependent and was not standardized given the retrospective nature of the study. However, prior studies have not shown a significant correlation between remnant preservation and risk of cyclops lesion formation, postoperative extension deficit, or graft failure.[2,26] In the current study, only 252 patients met inclusion criteria, and the graft failure rate was relatively low at 5.9%, making the power to detect a significant difference in this outcome low. Despite these limitations, the current study is clinically relevant in that it provides further evidence that intercondylar notch size is a significant risk factor for failure after ACLR and may also be associated with increased risk of knee stiffness. Larger prospective studies are needed to confirm the results of the current study and assist in further delineating risk factors of failure, knee stiffness, and subsequent meniscal injury after ACLR. Future studies should also evaluate ways to minimize the risk of graft failure in this at-risk patient population with a smaller intercondylar notch.

CONCLUSION

Intercondylar notch size <16 mm was associated with graft failure after primary anatomic ACLR. Based on the study results, patients with a smaller notch size should be counseled on their significantly increased risk of graft failure after ACLR. Further research is needed to determine if this risk of graft failure can be mitigated to improve patient outcomes.

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ORCID iDs

Jonathan D. Hughes https://orcid.org/0000-0002-1298-7514
Stephanie A. Boden https://orcid.org/0000-0003-1995-1116
Brian Godshaw https://orcid.org/0000-0001-9554-0410

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