

Intercondylar Notch Size Can Be Predicted on Preoperative Magnetic Resonance Imaging



Ravi Vaswani, M.D., Sean J. Meredith, M.D., Jayson Lian, M.D., Ryan Li, M.D., Michael Nickoli, M.D., Freddie H. Fu, M.D., and Volker Musahl, M.D.

Purpose: To develop a standardized method of intercondylar notch measurement on preoperative radiographs and magnetic resonance imaging (MRI) and validate that it could predict intraoperative notch measurements. **Methods:** The charts and imaging of 50 patients undergoing anterior cruciate ligament reconstruction were reviewed. A standardized method of intercondylar notch measurement on radiographs and MRI was used by 3 blinded reviewers. Arthroscopic measurements were made by the surgeon who was blinded to the imaging measurements. Interrater reliability was determined between reviewers and between imaging and arthroscopic measurements using interclass correlation coefficients (r). **Results:** The average notch base width was 16.5 (\pm 2.7) mm on MRI, 19.0 (\pm 3.4) mm on radiographs, and 15.8 (\pm 3.0) mm on arthroscopic measurement. The radiographic notch base width measurements were on average 1.2 times greater than the arthroscopic measurements. There was no significant difference between males and females in notch base width (16.7 mm vs 15.3 mm, $P = .19$) or area (312.5 mm² vs 284.3 mm², $P = .17$). Interrater reliability was excellent between the reviewers for notch base width measurement on both MRI ($r = 0.91$) and radiographs ($r = 0.95$). Good-to-excellent interrater reliability between notch base width measurements on MRI and arthroscopy ($r = 0.78, 0.73, 0.7$) and fair-to-good interrater reliability between notch base width measurements on radiographs and arthroscopy were found ($r = 0.61, 0.58, 0.55$). **Conclusions:** This study introduces a reliable method of using preoperative MRI to predict intercondylar notch width during arthroscopy. This data can be used to identify patients with narrow notches preoperatively. **Level of Evidence:** Level III, diagnostic study.

Intercondylar notch size is an important consideration in anterior cruciate ligament (ACL) injuries and surgical reconstruction. Smaller notch sizes have been shown to predispose patients to ACL tear and may contribute to the greater incidence of ACL tears seen in female patients.^{1,2} Notch size may also be a predictor of surgical difficulty during reconstruction, as passage of the graft can be difficult in small notches, and some surgeons may perform a notchplasty, or removal of a

small portion of the lateral wall of the notch, to adequately visualize the graft insertion site on the femur or to prevent graft impingement.^{3,4} Notchplasty has been shown to have associated morbidity, including tunnel widening,⁵ altered graft biomechanics,⁶ and increased blood loss.⁷

Many studies have demonstrated ways to measure intercondylar notch size using the notch width^{4,8} or the notch width index.⁹⁻¹² However, these studies largely focus on the relationship between ACL injury and notch size, and the techniques to measure notch size have not been validated. In addition, there have been conflicting reports in the literature as to whether preoperative notch size measurements on radiographs and magnetic resonance imaging (MRI) are accurate.¹³⁻¹⁵

The ability to predict a small notch, and potentially increased surgical difficulty, especially with large grafts and bone-tendon grafts, would aide surgeons in preoperative planning. The purpose of this study was to develop a standardized method of notch measurements on preoperative radiographs and MRI and validate that the method could predict intraoperative notch measurements. It was hypothesized that standardized measurement of the intercondylar notch on

From the Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, U.S.A.

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Address correspondence to Volker Musahl, M.D., University of Pittsburgh, Department of Orthopaedic Surgery, Freddie Fu Sports Medicine Center, Rooney Sports Complex, 3200 S Water St., Pittsburgh, PA 15203. E-mail: musahlv@upmc.edu

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preoperative radiographs and axial MRI would correlate with intraoperative measurements.

Methods

Approval from the Institutional Review Board was obtained. The charts of 59 consecutive patients undergoing ACL reconstruction by a single sports medicine fellowship-trained orthopaedic surgeon from April 2016 to June 2017 were retrospectively reviewed by the 3 of the authors (R.V., S.M., R.L.), who were either orthopaedic residents or fellows. Inclusion criteria were patients who had preoperative Rosenberg view (Standing 45° flexion posteroanterior) radiographs, axial fluid-sensitive MRI sequences, and standardized intraoperative intercondylar notch measurements. Exclusion criteria were patients who did not have preoperative imaging or intraoperative measurements available for review.

Standardized, arthroscopic intercondylar notch measurements have been previously used in the literature.^{8,16,17} With the patient supine and knee flexed to 90°, the notch was viewed from a standard lateral portal and the arthroscopic ruler (Trukor depth gauge; Smith & Nephew, Andover, MA) was inserted into the knee through the medial portal. Then, 5 measurements were made at the intercondylar notch entrance: width at the base, middle, and apex of the notch, and height at the medial and lateral walls of the notch (Fig 1). These

measurements were performed just prior to femoral tunnel drilling on each patient in the same order. The preoperative imaging measurements were made after the surgery, so the surgeon was blinded to the imaging measurements.

A standardized method was developed for image selection and measurement of the intercondylar notch on radiographs and MRI. Three independent reviewers assessed each image and were blinded to the intraoperative measurements. The single-axial, fluid-sensitive sequence image with the best visualized contour of the entire notch outlet was agreed upon by each reviewer. The notch base width was measured from the lateral femoral condyle medial articular cartilage margin to the medial femoral condyle lateral articular cartilage margin. The notch width was also measured at one-thirds and two-thirds of the height of the notch. The height of the medial and lateral walls of the notch were measured, and the trapezoidal area created by these lines defined the notch area (Fig 2). This imaging measurement method mimics how intraoperative notch measurements are taken. On preoperative Rosenberg radiographs, the notch width at the base also was measured from the central margins of the subchondral bone of the medial and lateral femoral condyles (Fig 3). Interrater reliability between the preoperative imaging and intraoperative arthroscopic measurements was calculated using interclass

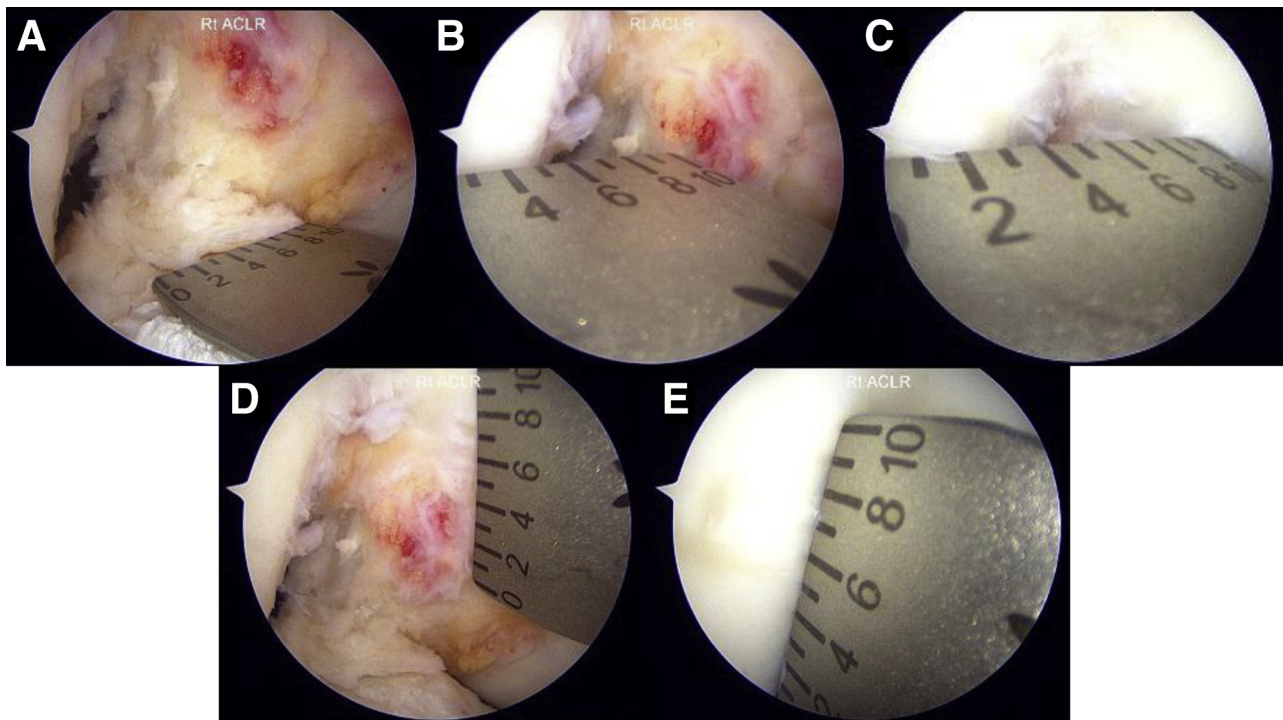


Fig 1. Example of arthroscopic notch measurements of a left knee with the patient supine and knee flexed to 90°; the arthroscopic ruler (Trukor depth gauge, Smith & Nephew, Andover, MA) is introduced through the medial portal and the following measurements are made: (A) notch width at base, (B) notch width at mid height, (C) notch width at apex, (D) medial wall height, (E) lateral wall height.

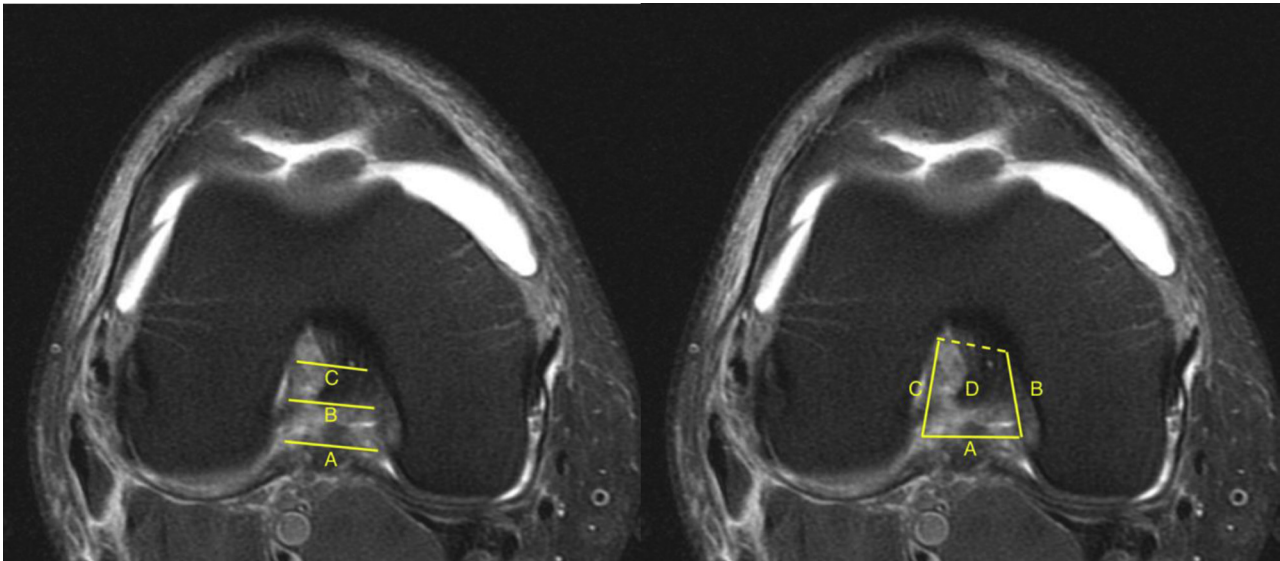


Fig 2. Example of magnetic resonance imaging notch measurements on selected T2 axial sequence of a left knee. Left: (A) notch width at base, (B) mid height, (C) apex. Right: (A) notch width at base, (B) medial and (C) lateral wall height, and (D) area.

correlation coefficients (r). These coefficients were graded as excellent (>0.75), good (0.60-0.74), fair (0.40-0.59), or poor (<0.40). A single interclass correlation coefficient was calculated between the 3 reviewers' measurements. For patients with the smallest and largest notches, the Spearman correlation coefficient was used. This is a nonparametric correlation coefficient that is ideal for small data sets. A value of 1 indicates a perfect increasing relationship between the 2 measurements, a value of -1 indicates a perfect decreasing relationship, and a value of 0 indicates there is no relationship. Secondary subgroup analyses also were performed comparing male and female notch characteristics as well as revision and primary ACL reconstruction.

Results

Of the 59 patient charts and imaging reviewed, 9 patients were excluded from the study (3 did not have Rosenberg view radiographs, 2 did not have MRI available for review, 4 did not have arthroscopic measurements). Fifty patients were included in the final analysis, 27 of whom were female (54%) and 23 of whom were male (46%), with an average age of 25.8 years (range 12-60 years). The cohort included 37 primary ACL reconstructions, 11 revision ACL reconstructions, and 2 posterolateral bundle augmentation ACL procedures.

On MRI, the average notch base width was 16.5 mm (± 2.7 mm), and the average notch area was 271.4 mm² (± 62.9 mm²) (Table 1). Average notch base width on radiographs was 19.0 mm (± 3.4 mm). During arthroscopic measurement, the average notch base width was 15.8 mm (± 3.0 mm), and the average notch area was 297.3 mm² (± 71.5 mm²). There was no significant difference between the MRI or arthroscopic

measurements of notch width base ($P = .21$), medial wall height ($P = .10$), or notch area ($P = .06$). The notch width at mid height ($P < .001$) and at the apex ($P < .001$) was significantly greater on MRI compared with arthroscopy (Table 1). The lateral wall height was significantly greater on arthroscopy than MRI ($P < .001$). The radiographic notch base width measurements were greater than the arthroscopic measurements ($P < .001$) by an average factor of 1.2 (Table 2).

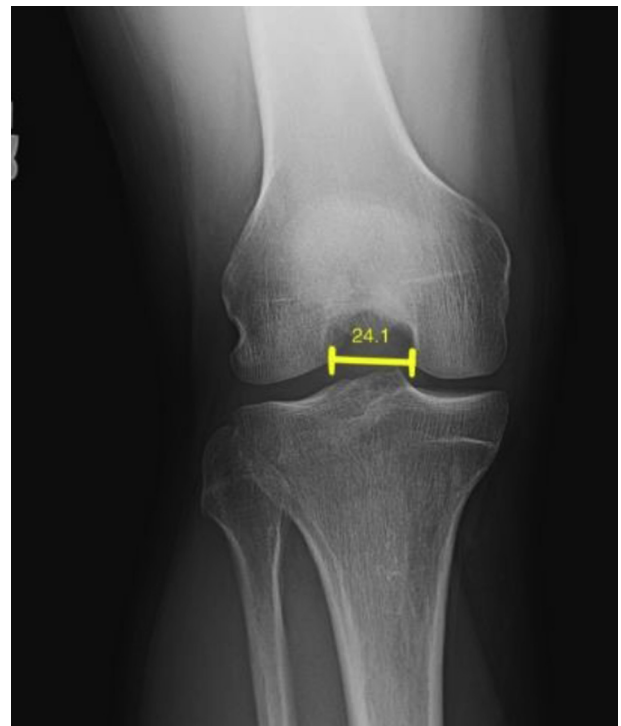


Fig 3. Example of notch base width measurement on Rosenberg view plain film radiograph of a right knee.

Table 1. Intercondylar Notch Measurement: MRI Versus Arthroscopy Comparison

	MRI	Arthroscopic	<i>P</i> Value
Width at base, mm	16.5 ± 2.7	15.8 ± 3.0	.21
Width at mid-height, mm	19.0 ± 2.5	13.5 ± 2.5	<.001
Width at apex, mm	15.9 ± 2.4	8.56 ± 1.4	<.001
Medial wall height, mm	16.3 ± 2.1	17.1 ± 3.1	.10
Lateral wall height, mm	16.3 ± 2.1	20.3 ± 2.3	<.001
Area, mm ²	271.4 ± 62.9	297.3 ± 71.5	.06

Values are shown as averages ± standard deviation.
MRI, magnetic resonance imaging.

Interrater reliability was excellent between the 3 reviewers for measurement of notch base width on both MRI ($r = 0.91$) and radiographs ($r = 0.95$) as well as for notch width at mid-height ($r = 0.84$), notch medial wall height ($r = 0.81$), and notch area ($r = 0.88$) on MRI. Reliability was good for notch width at the apex ($r = 0.70$) and notch lateral wall height ($r = 0.72$) (Table 3). For all 3 reviewers, there was good-to-excellent interrater reliability between notch base width measurements on MRI and arthroscopy ($r = 0.78, 0.73, 0.7$), and fair-to-good interrater reliability between notch base width measurements on radiographs and arthroscopy ($r = 0.61, 0.58, 0.55$) (Table 4).

For the narrowest notches (base width <12 mm) interrater reliability as measured by Spearman correlation coefficient was good-to-excellent between reviewers for MRI (1.00, 0.66, 0.83) and radiographs (0.83, 0.94, 0.66) and was good between MRI and arthroscopy for each reviewer (0.68, 0.68, 0.66). Reliability was poor between radiographs and arthroscopy for the smallest notches (0.34, -0.06, -0.06). For the largest notches (width base >20 mm), interrater reliability was excellent among reviewers for MRI (0.87, 0.90, 0.87) but was poor for radiographs (0.20, -0.10, 0.10), between MRI and arthroscopy (0.3, -0.29, -0.29), and between radiographs and arthroscopy (0.29, 0.87, 0.29).

In the male versus female subgroup analysis, male patients were significantly older (31.1 vs 21.3 years, $P = .004$). There was no significant difference in arthroscopic measurements of notch base width (16.7 mm vs 15.3 mm, $P = .19$) and area (312.5 mm² vs 284.3 mm², $P = .17$) between male and female patients (Table 5).

In comparison of the revision with the primary reconstructions, there was no significant differences found in terms of notch base width on arthroscopy (15.3 mm vs 15.9 mm, $P = .49$) and on MRI (16.2 mm

Table 2. Intercondylar Notch Measurement: Radiograph Versus Arthroscopy Comparison

	Radiograph	Arthroscopic	<i>P</i> Value
Width at base, mm	19.0 ± 3.4	15.8 ± 3.0	<.001

Values are shown averages ± standard deviation.

Table 3. Interrater Reliability Coefficients

	Reviewer 1 vs Reviewer 2 vs Review 3
MRI width at base	0.91
MRI width at middle	0.84
MRI width at apex	0.70
MRI medial wall height	0.81
MRI lateral wall height	0.72
MRI area	0.88
Radiographic notch base width	0.95

MRI, magnetic resonance imaging.

vs 16.6 mm, $P = .73$). The revision and primary groups also had a similar proportion of males (54.5% vs 43.5%, $P = .52$).

Discussion

The study's hypothesis that standardized measurements of intercondylar notch width on preoperative imaging would correlate well with intraoperative arthroscopic measurements was confirmed. The proposed method is reliable and is predictive of intraoperative notch size. Furthermore, this method is widely applicable, as it is routine practice to obtain MRI before ACL reconstruction. Surgeons can use this method to adjust their operative plan and anticipate intraoperative challenges to enhance individualized ACL reconstruction.

Various methods of intercondylar notch size measurement have been proposed in the literature. However, they lack strong interrater reliability and arthroscopic validation. The different methods include absolute notch width,^{2,4,11,18} notch width relative to the size of the femoral condyles,^{9,12,19} as well as measurement on computed tomography scan²⁰ and radiographs.¹⁵ Most studies have assessed notch size as a risk factor for ACL injury. However, as correlation with arthroscopy was not the primary goal of these studies, they do not measure the notch in a similar fashion to how it is viewed during arthroscopy with the knee flexed.² Other studies do not account for the width of the articular cartilage that is clinically relevant during arthroscopy.²⁰

The original report attempting to validate the use of radiographs and MRI for measuring the intercondylar

Table 4. Preoperative Imaging Measurement Versus Arthroscopic Measurement Correlation Coefficients

	MRI (reviewer 1) vs Arthroscopy
MRI width at base	0.78
MRI width at middle	0.51
MRI width at apex	0.43
MRI medial wall height	0.05
MRI lateral wall height	0.20
MRI area	0.56
Radiographic notch base width	0.61

MRI, magnetic resonance imaging.

Table 5. Female Versus Male Intercondylar Notch Width

	Female	Male	P Value
Arthroscopic notch base width, mm	15.3	16.7	.19

notch evaluated 10 cadaveric knees and showed that MRI was more reliable than plain film radiographs.¹³ Radiographic measurements were significantly different than cadaveric dissection measurements, and the authors attribute the inconsistency to the fact that a small degree of rotation of the knee creates a large difference on the radiograph. A subsequent study showed that notch width measurements on preoperative radiographic Rosenberg view correlated well with intraoperative measurements during ACL reconstruction.¹⁴ Given the discrepancy, Anderson et al.¹⁵ lined the intercondylar notch of 10 cadavers with a barium marker and showed that rotation of the knee was a problem in accurately measuring the intercondylar notch size on radiographs as compared to direct measurements. More recently, Vrooijink et al.¹⁷ found excellent interrater reliability with preoperative MRI notch width measurements but no correlation between MRI and intraoperative arthroscopic measurements; however, they did not measure the notch entrance in a way that would mirror the notch view during arthroscopy and did not account for the articular cartilage on the femoral condyles. Even 3-dimensional notch volumes from computed tomography have been used to assess notch size, but the correlation to dissection measurements is still lacking.²⁰

The method presented here demonstrates a reliable, strong correlation between MRI and arthroscopic measurement of the notch base. The margins of the notch base are easily identifiable on arthroscopy and on MRI, so the surgeon likely measured a similar distance as the MRI reviewers. Correlation was fair for width measurement at the mid height and apex, likely due to the variability in the level at which these measurements were performed during arthroscopy. Unlike on MRI, where one-third the height was used to measure at the same height on each patient, the arthroscopic measurements of width at mid height and at the apex were done based on the surgeon's estimation of level of the notch. Correlation was poor for medial and lateral wall height, which was likely due to the lack of a standardized point at the notch apex at which the wall height was measured. During arthroscopy and MRI, it was often difficult to tell exactly where the wall ended or if it should be measured to the apex. Therefore, the notch base width was the most standardized measurement and could help identify patients with smaller notches. Indeed, for the smallest notches (base width < 12 mm), Spearman correlation coefficient was good-to-excellent between reviewers on MRI and good between MRI and arthroscopic measurements. This shows that in patients with

narrow notches, surgeons would likely be able to correctly identify the potentially challenging notch morphology.

Small notch size also has been cited as an indication for a notchplasty,²¹ which is associated with tunnel widening,⁵ altered graft biomechanics,⁶ and increased blood loss.⁷ The results presented in this study demonstrate that surgeons can accurately predict intercondylar notch size on preoperative imaging. This information could allow the surgeon to plan accordingly for a smaller notch and avoid a notchplasty. Modifications to the surgical plan could include alteration of arthroscopic portal placement to facilitate visualization of the anatomic insertions of the ACL and placement of the graft in the correct position.

No significant sex differences were found for notch base width and notch area on arthroscopic measurements. Previous studies have investigated the relationship between sex and notch size, but the results have varied. An MRI study of 48 healthy patients found female sex was associated with smaller notch volume than male sex, but there was no significant difference after controlling for patient height and weight.²² Another study of more than 200 patients analyzed the sex relationship but did not find a significant difference in notch width index.³ The largest cohort of more than 700 high school athletes showed that female athletes had a smaller notch width index on tunnel view radiographs than their male counterparts.¹² The results presented here demonstrate that female patients may not have smaller notch sizes than male patients.

Future studies may use this method to determine whether it would help surgeons adapt their preoperative plan, such as with graft selection, graft size, and portal placement. Studies also may investigate whether the improvements in preoperative planning would allow for decreased patient morbidity, more individualized ACL reconstruction, improved patient outcomes, and decreased rate of revision surgery.

Limitations

Limitations of this study include the sample size and retrospective nature. The sample size of 50 patients has been used in previous studies, and given that a consistent correlation was found, a larger sample size could be argued to be unnecessary. In addition, there was variation in the radiographic and MRI technique and quality, which could introduce some error in the measurements. However, this may represent actual practice settings in which this method would be used, and it is important to have a method that is practical and widely applicable for surgeons. Furthermore, the measurements were made on 2-dimensional imaging, as this is the most clinically applicable scenario, but this may misrepresent the 3-dimensional notch morphology experienced intraoperatively.

Another limitation is that each reviewer performed one set of measurements, so intrarater reliability was not available. The inclusion of revision ACL patients also may be considered a limitation of this study. Notch size may change following primary ACL reconstruction if a notchplasty is performed though this has not been proven in the literature. In this cohort, only 1 patient undergoing revision ACL had a previous notchplasty, so the results of the other revision patients may still be applicable. Finally, although arthroscopic measurement of the intercondylar notch has been described in the literature, it may not be considered the gold standard method of measurement, and since only the surgeon made the arthroscopic measurements, the reliability of this method is not available. However, no true gold standard has been identified in the literature, and knee arthrotomy would not be ethical for this purpose. Furthermore, arthroscopic measurements are the most clinically relevant, as surgeons base clinical decisions on their view of the notch during arthroscopy.

Conclusions

This study introduces a reliable method of using preoperative MRI to predict intercondylar notch width during arthroscopy. This data can be used to identify patients with narrow notches preoperatively.

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