Published in final edited form as:

Am J Sports Med. 2019 February ; 47(2): 303–311. doi:10.1177/0363546518823556.

Anatomical Features of the Tibial Plateau Predict Outcomes of ACL Reconstruction within 7 Years after Surgery

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Abstract

Background: Multiple anatomical features of the femoral condyles and tibial plateau have been shown to influence knee biomechanics and risk of anterior cruciate ligament (ACL) injury. However, it remains unclear how these anatomical factors affect the midterm outcomes of ACL reconstruction.

Hypothesis: Decreased femoral notch width, increased posterior and coronal slopes, and decreased concavity of the tibial plateau are associated with inferior clinical, patient-reported and osteoarthritis-related outcomes 7 years after ACL reconstruction.

Study Design: Cohort Study (level 3).

Methods: Prospectively collected data from 44 patients who did not have a subsequent graft or contralateral ACL failure within 7 years after unilateral ACL reconstruction were reviewed (23.7±9.2 years; 64% women). Notch width (after notchplasty), posterior slopes of the medial and lateral tibial plateau, maximum depth of the medial tibial plateau, and coronal tibial slope were measured from magnetic resonance images. Anatomical predictors of side-to-side differences in AP knee laxity (KT-1000 Knee Arthrometer), KOOS scores, medial joint space width and side-to-side differences in OARSI score, measured at 7 years, were identified using linear regression (bivariate) and stepwise regression (multivariate).

Results: Increased posterior slope of the lateral tibial plateau was associated with increased side-to-side difference in knee laxity (bivariate model only), increased side-to-side difference in OARSI score, and decreased KOOS sub-scores ($R^2 > .10$, $p < .05$). Increased posterior slope of the medial tibial plateau was associated with a higher side-to-side difference in OARSI score (bivariate model only) and lower KOOS sub-scores ($R^2 > .11$, $p < .03$). Increased coronal tibial slope was associated

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with lower KOOS sub-scores ($R^2 > .11$, $p < .03$). Decreased medial tibial depth was associated with increased knee laxity as well as decreased KOOS quality of life and symptoms sub-scores ($R^2 > .12$, $p < .03$). Postoperative notch width was not a significant predictor for any of the surgical outcomes. None of the anatomical features were predictive of medial joint space width narrowing.

Conclusions: Results partially support our hypothesis and highlight the importance of knee anatomy on several outcomes of ACL reconstruction in patients without subsequent graft or contralateral ACL injuries. Increasing slopes in coronal and sagittal plane along with decreasing concavity of the medial tibial plateau lead to less favorable outcomes 7 years after surgery.

Keywords

ACL; Knee; Anatomy; ACL Reconstruction; Outcomes

INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction surgery has shown promising results in restoring the gross stability of a symptomatic ACL-deficient knee, but significant long-term problems affecting knee health and patient outcomes persist, including high rates of re-injury, poorer patient reported outcomes, and a high risk for development of early onset posttraumatic osteoarthritis (OA).^{34,38,43} Accordingly, investigations of the factors affecting outcomes of ACL reconstruction are of great clinical significance to improve short- and long-term outcomes. The influence of patient- (e.g., age, activity level, sport participation),^{10,12,43} surgical- (e.g., graft type, size),^{3,18,20,25} and rehabilitation-related (e.g. neuromuscular and physical training)^{23,37} factors on ACL reconstruction outcomes have been the focus of many research efforts. In contrast, little is known about how a patient's anatomical features of the knee joint may influence outcomes. A better understanding of relationships between joint geometry and ACL outcomes would provide insight into which patients may or may not do well with surgical treatment.

The links between the complex morphological features of tibiofemoral joint and its biomechanics (loads and motion) are well documented;^{21,29,35,36,46} Multiple anatomical indices including the tibial plateau morphology (posterior slope and concavity),^{4,22,32,36,48} tibial eminence size,⁴⁷ and femoral inter-condylar notch size^{39,46,50} have been associated with increased ACL loading and risk of injury. Among those, there is strong evidence that posterior tibial slope (i.e, the anterior elevation of the tibial plateau is greater than the posterior elevation)^{4,19,22,32} and femoral notch width^{39,46,50} are primary anatomical risk factors for ACL injuries. A few recent studies have also investigated the effect of posterior tibial slope in the sagittal plane^{9,30,31,43,49} and notch width^{30,31} on risk of secondary ACL injury. Despite the significance of reinjury following ACL reconstruction, particularly among adolescents, many patients do not present with a reinjury. Therefore, it is important to understand if these anatomical features influence the outcomes of ACL reconstruction in patients who do not have a reinjury. Our objective was to test the associations between key anatomical features of the knee and clinically relevant outcomes of ACL reconstruction. We hypothesized that decreased postoperative femoral notch width, increased posterior and coronal slopes, and decreased concavity of the tibial plateau are associated with inferior

clinical, patient-reported and OA related imaging outcomes 7 years after ACL reconstruction.

METHODS

Subjects

A subset of participants enrolled in an ongoing clinical trial (NCT00434837) investigating the effects of initial graft tension on outcomes ACL reconstruction with autograft was used for this study.^{1,18} The subset included those patients that did not have a subsequent graft or contralateral ACL failure after the index procedure (as determined by clinical exam and verified by MRI) and those that were not lost to follow-up. The analyses presented here are unique and address hypotheses different from those of the original study.^{1,18} The trial was approved by the Institutional Review Board at Rhode Island Hospital, and all patients provided informed consent. Patients were recruited from the clinics of three surgeons (PDF, MJH, RMS) over a 3-year period as previously described.^{1,18} Inclusion criteria comprised an age range of 15 to 50 years, a Tegner activity score ≥ 2 , and candidacy for unilateral patellar tendon or hamstring autograft reconstruction. Exclusion criteria were history of injury to either knee, evidence of knee OA on preoperative radiographs, diseases predisposing them to articular cartilage damage, moderate-size fissures or lesions of the articular cartilage,¹⁶ meniscal tears involving greater than the central third of the meniscus, or increased laxity (grade >1) in the posterior cruciate ligament, medial collateral ligament, and lateral collateral ligament relative to the contralateral knee.^{1,18} Of the 557 patients screened, 335 were excluded as they did not meet the inclusion criteria and 112 patients declined participation, leaving 90 patients available for inclusion in the original trial.^{1,18}

ACL reconstruction was performed with either a patellar tendon or 4-strand hamstring autograft, the selection of which was based on surgeon and/or patient preference. A femoral notchplasty was routinely performed. All surgeons followed the same surgical technique in an effort to minimize variability.¹⁸ As the original trial was designed to compare two graft tension protocols, one that restored AP laxity to that of the contralateral leg (graft firmly tensioned with the knee at full extension; the low tension treatment), and the other that constrained knee laxity by 2 mm (graft firmly tensioned with the knee at 30 degrees flexion; the high tension treatment), which were randomly assigned as previously described.¹⁸ Postoperatively, all patients followed a standardized rehabilitation program with the goal to return to sport at 6 months.^{5,18} Multiple clinical, patient-reported and imaging outcomes related to OA were measured at 7-year postoperative follow up visit. Patients were pooled for the current analysis as both groups had similar outcomes.^{1,18} However, the tension group was considered as a potential explanatory variable.

Of the 90 patients enrolled in the trial, 53 had their knee MR imaged at 3 years, a time point that a majority of subjects first underwent MR imaging. Of these 53 patients, 44 had no subsequent injuries and completed their 7-year onsite visit. This subset of 44 patients had a mean age of 23.7 ± 9.2 years at the time of surgery, a baseline Tegner activity level of 5.6 ± 2.2 , 28 (64%) were female, 24 (55%) had high-tension graft reconstruction and 15 (34%) had hamstrings tendon grafts.

Outcome Measures

The following outcomes, quantified at 7 years, were used in the current analyses:

AP Knee Laxity: Anterior-posterior (AP) laxity values for both knees were measured using the KT-1000 Knee Arthrometer (MEDMetric Corporation, San Diego CA) by a trained physical therapist.¹¹ Three manual maximum tests were performed, and the displacement readings averaged. The difference between legs (surgical knee – contralateral intact knee) was calculated and used for the analysis.

KOOS: The Knee Injury and Osteoarthritis Outcome Score (KOOS)⁴¹ was implemented to assess patient reported outcomes. The KOOS evaluates five domains: 1) knee related quality of life (KOOS-QOL), 2) sports and recreation function (KOOS-sport), 3) activity of daily living (KOOS-ADL), 4) symptoms (KOOS-symptoms), and 5) pain (KOOS-pain). The sub-scores were presented on a scale ranging from 0 to 100, with 100 indicating a perfect knee.

Medial JSW: Medial minimum joint space width (mJSW) measurements were obtained from standardized radiographs using the semi-flexed metatarsophalangeal (MTP) view.^{8,18} The minimum joint space width of the medial compartment was calculated using a validated semi-automated algorithm.^{14,15} The difference in mJSW between legs (surgical knee – contralateral intact knee) was calculated and used for this analysis.

OARSI Radiographic Score: The overall condition of the joint was assessed using the modified Osteoarthritis Research Society International (OARSI) radiographic grading scale.²² Using posterior-anterior and lateral radiographs of both knees, a grade of 0 (normal) to 4 (severe) was assigned to two radiographic features: osteophyte formation and joint space narrowing. In addition, sclerosis, attrition, and ligament calcification were assessed on a dichotomous scale. An experienced musculoskeletal radiologist scored all films while blinded. The difference in OARSI score between legs (surgical knee – contralateral intact knee) was calculated and used for the analysis.

Anatomical Predictors

Subjects were scanned at using a 3T scanner (Tim Trio, Siemens, Erlangen Germany) and a surface knee coil using standardize protocol and acquisition parameters using a three-dimensional T1-weighted FLASH sequence (RT/ET/FA: 20ms/7.6ms/12; FOV: 160mm; Matrix: 512X512 pixels, slice thickness/gap: 1.5/0mm). These images were used to quantify several anatomical features of the femoral condyles and tibial plateau (Figure 1). A single examiner (DY) performed the anatomical measurements while blinded to the patients' identity. To assess the reliability of the measurements, a subset of images was randomly selected (n=20) and blindly analyzed by another independent examiner (AMK). Variance component analysis was performed to calculate the intraclass correlation coefficients (ICCs) for each quantified anatomical index.¹⁷

Femoral Notch Width: Width of the femoral notch was measured in coronal plane, parallel to a line along the most inferior aspects of the femoral condyles.³⁹ The measurement was done at the middle of the ACL attachment.⁵⁰ The ICC for notch width was 0.912.

Posterior Tibial Slope: The posterior slopes of the medial and lateral tibial plateaus were measured using the techniques described by Hudek et al.²⁴ Briefly, a central sagittal slice, in which the tibial attachment of the PCL, the intercondylar eminence, and the anterior and posterior tibial cortices appeared in a concave shape, was selected. Then, one cranial circle (touching the anterior, posterior, and cranial tibial cortex) and one caudal circle (touching the anterior and posterior cortex) was fitted to the tibial head. The line connecting the center of two circles was defined as longitudinal tibial axis.²⁴ This technique has been shown to be highly repeatable and independent of proximal tibial length covered in the MR image.³³ The posterior slope of the tibial plateau was measured in a sagittal slice at the center of each medial and lateral plateau as the angle between a line that joined the peak points on the anterior and posterior rims of the plateau and a line perpendicular to longitudinal axis of the tibia.²¹ This method has been shown to be able to quantify the tibial slope with a sensitivity of 1°.²² The ICC for posterior tibial slope were 0.830 (medial) and 0.890 (lateral).

Coronal Tibial Slope: The slope of the tibial plateau in the coronal plane was measured using the technique described by Hashemi et al.²¹ Briefly, the longitudinal axis of the tibia was established in the coronal slice passing through the approximate centroid of the tibial plateau. This was done by determining the midpoint of the medial-to-lateral width of the tibia at two points located approximately 4 to 5 cm apart and as distally in the image as possible. The extended line connecting the two midpoints represents the longitudinal (or diaphyseal) axis of the tibia in the coronal plane. The coronal slope of the tibial plateau was then measured as the angle between a line joining the peak points on the medial and lateral aspects of the plateau and the line perpendicular to the longitudinal axis.²¹ The ICC for coronal tibial slope was 0.933.

Medial Tibial Depth: The medial tibial depth was measured as the perpendicular distance between a line connecting the anterior and posterior rims of the medial tibial plateau and the deepest point of the medial plateau in the same slice that the medial slope was measured.²¹ The ICC for medial tibial depth was 0.849.

Statistical Analyses

Simple linear regression analyses were performed to investigate the relationships between each of the anatomical predictors and surgical outcome measures at 7 years (Bivariate Analyses). Additionally, stepwise regression analyses were used to identify the best predictive models for each surgical outcome. For the stepwise procedure, all anatomical and potentially important demographic variables (i.e., sex, graft type, age and tension group) were considered candidates for inclusion in the model. Statistical analyses were conducted by a senior biostatistician (GJB) using SAS statistical software Version 9.4 (SAS Institute Inc., Cary, NC). Statistical significance was determined based on $\alpha = .05$.

RESULTS

Descriptive statistics for the anatomical measures and 7-year surgical outcomes are presented in Table 1. Except for the posterior slopes of the medial and lateral tibial plateaus

($R^2=.62$, $p<.001$), there were no significant correlations among the potential anatomical predictors ($R^2<.08$, $p>.05$; Supplementary Figure S1).

Bivariate Associations between Anatomical Measures and 7-year Surgical Outcomes

Postoperative notch width was not a significant predictor for any of the surgical outcomes at 7 years ($R^2<.04$ and $P>.2$; Supplementary Table S1).

Increased posterior slope of the lateral tibial plateau was associated with increased side-to-side difference in knee laxity, decreased KOOS sub-scores and increased side-to-side difference in OARSI score at 7 years after ACL reconstruction. Lateral tibial slope explained between 11 to 18% of the observed variability in knee laxity, KOOS sub-scores and OARSI score. On average, every degree increase in lateral tibial slope was linked to increased side-to-side differences in knee laxity by 0.4 mm, decreased KOOS sub-scores by 1 to 4 points and increased side-to-side differences in OARSI score by 0.4 points (Table 2).

Increased posterior slope of the medial tibial plateau was associated with lower KOOS and higher side-to-side difference in OARSI score at 7 years. Medial tibial slope explained between 12 to 25% of the variations in KOOS and OARSI score. On average, every degree increase in medial tibial slope was linked to decreased KOOS by 2 to 6 points and increased side-to-side differences in OARSI score by 0.4 points (Table 3).

Increased slope of the tibial plateau in coronal plane was associated with lower KOOS sub-scores at 7 years. Coronal tibial slope explained between 12 and 27% of the variability in KOOS sub-scores. On average, every degree increase in coronal tibial slope was linked to decreased KOOS sub-scores by 2 to 5 points (Table 4). Additionally, there was some evidence that increased coronal tibial slope was associated with an increased OARSI score ($p=.079$).

Decreased maximum depth of the medial tibial plateau (shallow plateau) was associated with increased knee laxity as well as decreased KOOS quality of life and symptoms sub-scores. Medial tibial depth explained 13 to 23% of the variability in knee laxity, and the KOOS quality of life and KOOS symptoms sub-scores. On average, every millimeter decrease in medial tibial depth was linked to increased side-to-side differences in knee laxity by 1.6 mm as well as decreased KOOS quality of life and symptom sub-scores by 16 and 12 points, respectively (Table 5).

Stepwise Regression with Anatomical and Demographics Measures as Potential Predictors

The results of the stepwise regression models for each surgical outcome are presented in Table 6. The derived prediction model for knee laxity included only the medial tibial depth, explaining 19% of the variation in side-to-side difference in knee laxity. The model predicting the KOOS quality of life sub-score included sex, medial tibial slope, and medial tibial depth. Combinations of these three parameters explained 42% of the observed variation in KOOS quality of life sub-score. The combination of sex, graft type, medial and coronal tibial slopes produced the predictive model of the KOOS sports sub-score and explained 54% of the variation in this outcome. The KOOS subscore related to activities of

daily living was predicted by a combination of sex, graft type, lateral and coronal tibial slopes. These four parameters explained 54% of the variation observed in this outcome. The model to predict KOOS symptom sub-score included graft type, lateral tibial slope, and medial tibial depth, which explained 45% of the variation in the KOOS symptom sub-score. The combination of sex, graft type, lateral and coronal tibial slopes were best predictive of the KOOS pain sub-score and explained 54% of the variation in this outcome. None of the studied anatomical features were predictive of medial joint space width narrowing at 7 years. However, lateral tibial slope was the only predictor of OARSI score in the stepwise analysis and explained 15% of side-to-side difference at 7 years.

DISCUSSION

We determined that knee laxity, the KOOS sub-scores and OARSI score were influenced by the slopes of the tibial plateau in the coronal and sagittal planes, and the maximum depth of the medial tibial plateau 7 years after ACL reconstruction. The finding that these anatomical features, except for medial and lateral tibial slopes, were not correlated to one another suggests that they independently influence ACL reconstruction outcomes. Contrary to our hypotheses, we did not find any associations between post-operative femoral notch width, nor between the anatomical features and minimum joint space width in the medial compartment. Therefore, these results partially support our hypothesis, and highlight the importance of knee anatomy on several outcomes of ACL reconstruction in patients without subsequent graft or contralateral ACL injuries.

Subjects with steep posterior slope of the lateral tibial plateau had inferior outcomes with regards to increased knee laxity, decreased KOOS sub-scores and increased OARSI score. During weightbearing tasks, posterior tibial slope produces an anterior shear force component as an axial compression force is applied across the knee joint.¹⁹ Accordingly, an increased posterior tibial slope would lead to an increased anterior tibial shear force,³⁵ anterior tibial acceleration and translation,³⁶ and ACL strain.^{32,36} Posterior tibial slope has also shown to contribute to knee rotation in coronal (abduction)²⁹ and axial (internal tibial rotation)^{21,46} planes, which both can increase ACL loading.^{26,40} Several groups have shown significant increases in risk of graft failure in patients with steep lateral tibial slope.^{9,30,31,43,49} Our current findings suggest that while this increased ACL loading can lead to graft failure under injurious conditions, it may also result in inferior graft properties by overloading the healing tissue in patients that do not rupture their graft. The inferior graft properties could ultimately lead to unsatisfactory outcomes, in particular increased residual knee laxity.⁶ Increased knee laxity can also result in inferior knee function⁷ and increased cartilage degeneration in long term,²⁷ which could lead to unsatisfactory KOOS sub-scores and elevated OARSI score as seen here.

Likewise, the posterior slope of the medial tibial plateau has also been shown to contribute to anterior shear loading and joint rotation as well as ACL loading and risk of injury.^{21,22,29,46} Thus, it is possible that increased medial tibial slope can also overload the healing graft and ultimately result in unfavorable outcomes as suggested above. Increase medial tibial slope has also shown to result in increased cartilage loading under weightbearing conditions.²⁸ Combination of these effects can be manifested as inferior joint function,

increased pain and joint degeneration as reported here by decreased KOOS sub-scores and increased OARSI score. Considering the strong correlations between medial and lateral tibial slopes,²¹ it is possible that observed associations between medial tibial slope and surgical outcomes are also influenced by the lateral tibial slope. However, the stepwise analysis highlights the distinct effects with medial tibial slope influencing the KOOS quality of life and sports participation sub-scores, whereas lateral tibial slope influencing KOOS daily activities, symptoms and pain sub-scores along with OARSI score. The reasons for this are unclear and require further study.

Coronal tibial slope (the slope from the lateral edge of the tibial plateau to the medial edge) has been shown to influence knee rotations in the coronal and axial planes.⁴⁵ A positive slope represents a more elevated lateral tibial plateau than medial in the coronal plane. A greater coronal tibial slope has been associated with greater internal tibial rotation excursions, while a lower coronal tibial slope linked to a greater knee valgus.⁴⁵ Although coronal tibial slope has not been shown to influence the ACL injury risk, it is possible that excessive internal rotation and varus alignment in knees with high coronal tibial slope could lead to increased cartilage wear and degeneration. A recent study has shown a significant association between increased coronal tibial slope with increased risk of accelerated knee OA.¹³ Our observations of decreased KOOS sub-scores and a trend towards increased OARSI scores in subjects with high coronal tibial slopes further reinforce the importance of the coronal tibial slope and its potential effect in increased risk of posttraumatic OA. The importance of the coronal tibial slope on ACL reconstruction outcomes are further supported by the stepwise analysis indicating coronal tibial slope as a significant predictor of KOOS outcomes related to sports, daily activities and pain.

The maximum depth of the medial tibial plateau has been suggested as a surrogate for the extent of medial tibial plateau concavity.^{21,22} A deeper (more concave) medial tibial plateau will constrain the femoral condyle to a greater extent and may result in increased resistance to displacement of the tibia relative to the femur.²¹ Conversely, knees with shallower medial tibial plateau may be more prone to anterior directed translation of the tibia. Prior studies have shown significantly lower medial tibial depth in subjects with an injured ACL compared to matched uninjured controls.²² It has also shown that a flatter medial tibial plateau can result in increased medial cartilage pressure, possibly due to less congruency and smaller contact area between the curved femoral condyle and flat tibial plateau.²⁸ This increased instability can lead to higher residual knee laxity, which may in turn contribute to symptomatic knee and lower quality of life, in particular in presence of excessive cartilage loading and possible degeneration. The importance of medial tibial depth on AP knee stability is further highlighted by our stepwise analysis indicating that medial tibial depth is the sole predictor of the side-to-side differences in knee laxity at 7 years.

Interestingly, we did not see any associations between postoperative notch width and the outcomes of ACL reconstruction studied here. Given that a notchplasty (notch enlargement) is commonly performed during ACL reconstruction surgery, the impact of notch width on outcomes in the present study was likely minimized. Further studies are warranted to investigate if preoperative notch width can influence ACL reconstruction outcomes.

None of the studied outcomes were associated with minimum joint space width in the medial compartment. Structural assessments of joint space width via radiography are not very sensitive measures to detect changes in the early stages of OA,³⁶ which may have contributed to the observed lack of association. On the other hand, we identified significant associations between the anatomical features and the radiographic OARSI score, which focuses on degeneration of the whole joint and not just cartilage thickness. It is possible that we would see relationships between the anatomical features and joint space width at later follow up times after significant narrowing occurs.

There are several limitations to consider. Although the data were prospectively collected, the study was retrospective in that the research question was asked after the data were acquired. The bony features were measured from MR images acquired 3 years postoperatively as preoperative images were not available for all patients. Therefore, we assumed that the bony features of the joint would not have changed since the injury. Despite relatively high follow up rates, MR images at 3 years were only available for a subset of patients as MRI was added to the parent trial after 50% of the subjects were enrolled, reducing our subject numbers with MRI to 44, which in turn reduced the power of the study. Our study was 80% powered to detect anatomical measures that explain 18% or more of the variability in surgical outcomes. Finally, considering the available number of cases, male and female patients of all ages with different graft types (patellar tendon and hamstring tendon autografts) and tension conditions (tensioned to restore normal knee laxity or tensioned to over-constrain knee laxity) were pooled together, instead of subgroup analyses, which may have affected our findings. To minimize these potential effects and to confirm our observations in the bivariate analyses, we included these four demographic factors in our stepwise analyses. Graft tension was not a significant contributor to the models, which is in agreement with our previous observations indicating minimal graft tension effects on outcomes at 7 year follow-up.¹ While young age has been associated with higher-rates of graft failure,⁴³ ACL reconstruction outcomes have shown to be comparable across age groups in patients without subsequent injury.^{10,12} This is in agreement with our observations of age not being significant in any of the stepwise models. Controversies exist on the effect of graft type (i.e. hamstrings vs. quadriceps) and sex on the outcomes of ACL reconstruction with some studies suggesting significant effects and others demonstrating comparable outcomes.^{42,44} Sex and graft type were significant contributors to some of the stepwise models. However, any conclusions regarding their role would be premature, particularly given the lack of associations between sex and graft type with the studied outcomes in a bivariate setting ($p>0.05$ for all associations).

In conclusion, we determined that tibial slope in the sagittal and coronal plans and concavity of tibial plateau significantly influenced several of the clinical, patient-reported and imaging outcomes related to posttraumatic OA of ACL reconstruction. Increasing slopes in coronal and sagittal plane along with decreasing concavity of the medial tibial plateau lead to less favorable outcomes. The study provides a better understanding of the impact of bony geometry on ACL reconstruction outcomes, which may help clinicians inform patients and could potentially be used to guide rehabilitation and return to play decisions.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGEMENT

The research reported in this publication was supported by the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institutes of Health (R01-AR047910, R01-AR065462), the Lucy Lippitt Endowment, the RIH Orthopaedic Foundation, the Boston Children's Hospital Orthopaedic Surgery Foundation, and the National Football League Players Association through the Harvard Catalyst's Football Players Health Study. The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the funding agencies.

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Figure 1. Measurement techniques used to quantify notch width (NW), coronal tibial slope (CTS), medial tibial slope (MTS), medial tibial depth (MTD) and lateral tibial slope (LTS).

Table 1.

Descriptive statistics of the anatomical predictors and surgical outcomes at 7-year follow-up. NW = notch width; LTS = lateral tibial slope; MTS = medial tibial slope; CTS = coronal tibial slope; MTD = medial tibial depth; AP = anteroposterior; KOOS = Knee Osteoarthritis Outcome Score; mJSW = medial joint space width; OARSI = Osteoarthritis Research Society International; SD = standard deviation.

	Mean $\pm$ SD	Range
Predictors		
NW, mm	17.5 $\pm$ 3.1	12.1 – 24.6
LTS, degrees	6.6 $\pm$ 2.2	2.1 – 13.4
MTS, degrees	4.7 $\pm$ 1.9	0.2 – 7.3
CTS, degrees	2.9 $\pm$ 2.1	–1.2 – 8.8
MTD, mm	2.1 $\pm$ 0.7	0.9 – 3.6
Outcomes		
^a AP Knee Laxity, mm	1.6 $\pm$ 3.0	–6.0 – 8.3
KOOS-QoL	76.2 $\pm$ 22.7	6.3 – 100.0
KOOS-Sports	82.3 $\pm$ 19.3	20.0 – 100.0
KOOS-ADL	94.1 $\pm$ 10.6	52.9 – 100.0
KOOS-Symptoms	80.1 $\pm$ 16.8	32.1 – 100.0
KOOS-Pain	88.8 $\pm$ 20.0	11.1 – 100.0
^a Medial mJSW, mm	–0.1 $\pm$ 0.7	–2.5 – 1.2
^a OARSI Score	0.8 $\pm$ 2.3	–2.0 – 13.0

^aPresented as the difference between surgical and contralateral ACL intact leg (surgical-contralateral).

Table 2.

Regression coefficients for lateral tibial slope predicting each surgical outcome at 7-years. Significant associations are highlighted in bold.

Outcome	β (95% CI)	R ²	p-value
^a AP Knee Laxity	0.4 (0.0, 0.8)	.11	.044
KOOS-QoL	-4.3 (-7.2, -1.5)	.18	.004
KOOS-Sports	-3.2 (-5.7, -0.8)	.14	.013
KOOS-ADL	-1.8 (-3.1, -0.4)	.14	.014
KOOS-Symptoms	-2.8 (-5.0, -0.7)	.14	.013
KOOS-Pain	-3.3 (-5.9, -0.7)	.14	.014
^a Medial mJSW	-0.1 (-0.2, 0.1)	.02	.395
^a OARSI Score	0.4 (0.1, 0.7)	.15	.012

^aPresented as the difference between surgical and contralateral ACL intact leg (surgical-contralateral).

Table 3.

Regression coefficients for medial tibial slope predicting each surgical outcome at 7-years. Significant associations are highlighted in bold.

Outcome	β (95% CI)	R ²	p-value
^a AP Knee Laxity	0.4 (-0.1, 0.9)	.05	.155
KOOS-QoL	-5.8 (-9.0, -2.7)	.25	<.001
KOOS-Sports	-4.5 (-7.3, -1.8)	.20	.002
KOOS-ADL	-1.9 (-3.5, -0.3)	.12	.020
KOOS-Symptoms	-3.6 (-6.1, -1.1)	.17	.006
KOOS-Pain	-3.6 (-6.6, -0.6)	.12	.020
^a Medial mJSW	0.0 (-0.1, 0.1)	.00	.925
^a OARSI Score	0.4 (0.1, 0.8)	.12	.028

^aPresented as the difference between surgical and contralateral ACL intact leg (surgical-contralateral).

Table 4.

Regression coefficients for coronal tibial slope predicting each surgical outcome at 7-years. Significant associations are highlighted in bold.

Outcome	β (95% CI)	R ²	p-value
^a AP Knee Laxity	0.2 (-0.2, 0.7)	.03	.309
KOOS-QoL	-4.3 (-7.4, -1.1)	.16	.010
KOOS-Sports	-4.5 (-7.0, -1.9)	.23	.001
KOOS-ADL	-2.6 (-4.0, -1.2)	.27	<.001
KOOS-Symptoms	-2.8 (-5.2, -0.4)	.12	.024
KOOS-Pain	-4.9 (-7.6, -2.4)	.27	<.001
^a Medial mJSW	0.0 (-0.1, 0.1)	.01	.599
^a OARSI Score	0.3 (0.0, 0.7)	.08	.079

^aPresented as the difference between surgical and contralateral ACL intact leg (surgical-contralateral).

Table 5.

Coefficients associated with medial tibial depth for predicting surgical outcomes at 7-years. Significant associations are highlighted in bold.

Outcome	β (95% CI)	R ²	p-value
^a AP Knee Laxity	-1.6 (-2.9, -0.2)	.13	.028
KOOS-QoL	16.1 (6.8, 25.4)	.23	.001
KOOS-Sports	5.4 (-3.1, 13.9)	.04	.210
KOOS-ADL	3.9 (-0.8, 8.7)	.06	.106
KOOS-Symptoms	11.8 (4.7, 18.7)	.22	.002
KOOS-Pain	7.5 (-1.6, 16.5)	.06	.106
^a Medial mJSW	-0.2 (-0.5, 0.2)	.02	.395
^a OARSI Score	-0.4 (-1.5, 0.6)	.02	.430

^aPresented as the difference between surgical and contralateral leg (surgical-contralateral).

Table 6.

Stepwise regression analysis indicating significant predictors of surgical outcomes in a multivariate model with the demographic variables included. Notch width was not considered as it was not significant in any of the univariate analyses. Medial joint space width was not included in the table as it was not significant in any of the univariate analyses. LTS = lateral tibial slope; MTS = medial tibial slope; CTS = cor tibial slope; MTD = medial tibial depth; AP = anteroposterior; KOOS = Knee Osteoarthritis Outcome Score; OARSI = Osteoarthritis Research Society International; Int = intercept.

Outcome	Int	Sex (male)		Graft Type (Hamstring)		LTS		MTS		CTS		MTD		Model R ²
		β	P	β	P	β	P	β	P	β	P	β	P	
		(95% CI)		(95% CI)		(95% CI)		(95% CI)		(95% CI)		(95% CI)		
^a AP Laxity	5.5	---	---	---	---	---	---	---	---	---	---	-1.9 (-3.2, 0.6)	.006	.19
KOOS-QoL	70.8	-13.5 (-25.7, -1.3)	.034	---	---	---	---	-4.5 (-7.6, -1.4)	.002	---	---	15.1 (6.1, 24.2)	.009	.42
KOOS-Sports	109.7	-10.4 (-20.0, -0.9)	.034	11.9 (2.5, 21.4)	.015	---	---	-3.5 (-5.9, -1.1)	.006	-4.2 (-6.4, -2.1)	<.001	---	---	.54
KOOS-ADL	110.4	-5.9 (-11.2, -0.5)	.007	6.9 (1.5, 12.3)	.045	-1.4 (-2.6, -0.3)	.016	---	---	-2.55 (-3.7, -1.4)	<.001	---	---	.54
KOOS-Sympt	68.9	---	---	13.8 (5.1, 22.6)	.014	-2.7 (-4.6, -0.9)	.006	---	---	---	---	12.3 (5.9, 18.6)	<.001	.45
^a KOOS-Pain	119.7	-11.1 (-21.2, -1.0)	.035	13.0 (2.8, 23.2)	.015	-2.7 (-4.9, -0.6)	.016	---	---	-4.8 (-7.0, -2.6)	<.001	---	---	.54
^a OARSI Score	-1.8	---	---	---	---	0.4 (0.1, 0.7)	.017	---	---	---	---	---	---	.15

^aPresented as the difference between surgical and contralateral ACL intact leg (surgical-contralateral).