Risk Factors for Grade 3 Pivot Shift in Knees With Acute Anterior Cruciate Ligament Injuries

A Comprehensive Evaluation of the Importance of Osseous and Soft Tissue Parameters From the SANTI Study Group

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Background: Preoperative grade 3 pivot shift has been reported to be associated with higher rates of anterior cruciate ligament (ACL) failure, persistent instability, and inferior patient-reported outcomes. The etiology of a high-grade pivot shift is multifactorial, and numerous factors have been suggested to be responsible. More attention has recently been focused on injury to the anterolateral structures (ALS) as a risk factor for a grade 3 pivot shift.

Purpose: To determine risk factors for grade 3 pivot shift, including soft tissue and osseous parameters.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A prospective evaluation was undertaken of 200 consecutive patients undergoing acute ACL reconstruction (within 10 days of injury). An open exploration of the lateral side of the injured knee was performed at the time of the index procedure. Details regarding patient and injury characteristics were recorded, as were details of soft tissue injuries, including meniscal tears, ALS lesions, medial collateral ligament tears, and chondral injuries. Osseous parameters (tibial slope and condylar ratios) were determined per established magnetic resonance imaging protocols. A multivariate logistic regression with penalized maximum likelihood was used to identify risk factors associated with International Knee Documentation Committee (IKDC) grade 3 pivot shift.

Results: The mean ± SD age of the population was 28.3 ± 9.8 years; 67.5% of patients were male. Among patients, 35 (17.5%) had a high-grade pivot shift (IKDC grade 3), and 165 (82.5%) had a low-grade pivot shift (IKDC grades 1 and 2). Univariate and multivariate logistic regression analysis demonstrated that injury to the ALS was the only significant risk factor for grade 3 pivot shift (odds ratio, 13.49; 95% CI, 1.80-1725.53).

Conclusion: This comprehensive evaluation of soft tissue and osseous factors has identified that injury to the ALS is the most important risk factor for grade 3 pivot shift in acute ACL-injured knees.

Keywords: ACL; ALS; pivot shift; tibial slope

The pivot-shift test is the most specific physical examination test for the diagnosis of anterior cruciate ligament (ACL) injuries.[2,23,33,34,40] The pivot shift is a cornerstone of knee laxity assessment because it is an important preoperative predictor of clinical outcomes, serves to guide an appropriated index of suspicion for injury to the secondary restraints, and is the primary outcome measure that quantifies improvement in knee stability after ACL reconstruction. The presence of a high-grade preoperative pivot shift is associated with an increased risk of rerupture after ACL reconstruction and an increased risk of persistent rotatory instability after surgery as compared with a low-grade pivot shift.[11,34,37] Owing to increased knee rotational instability, patients with a grade 3 pivot shift experience poorer clinical outcomes.

However, the risk factors that predispose to a high-grade pivot shift have not been precisely defined. Although numerous potentially important factors have been identified, the confidence in the strength of their association

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with increased rotational instability has been limited, predominantly because of the methodological weaknesses of the studies reporting them.[12,13,16,18,32] Common limitations observed in the literature evaluating this topic include examination in awake patients (which is considerably less reliable than under anesthesia), very small study populations, and, most important, the evaluation of potential risk factors in isolation, without accounting for previously reported osseous and soft tissue parameters of importance or evaluating the complex interplay among them.

The aim of this study was to address the limitations of previous studies and to perform a comprehensive analysis of osseous and soft tissue risk factors for a high-grade pivot shift in knees with an acute ACL injury. The hypothesis of this study was that some of the previously reported risk factors would not show significant association with a high-grade pivot shift in an adequately powered study with a multivariate analysis.

METHODS

Institutional research board approval (4578/2014) was granted for this study. Consecutive patients presenting with an acute knee injury and clinical indications (positive Lachman and pivot-shift test results) of ACL rupture between January 2015 and April 2019 were considered for study eligibility. All patients underwent magnetic resonance imaging (MRI) within 5 days of injury with a 1.5-T MRI scanner (Symphony; Siemens Medical Solutions). Those patients with ACL rupture who underwent ACL reconstruction within 10 days of injury were prospectively enrolled in the study. It is institutional practice to perform acute ACL reconstruction within this time frame; therefore, patients presenting >10 days from injury or patients who preferred to postpone surgery were excluded from the study. Additional reasons for exclusion were multiligament injury, except medial collateral ligament (MCL), and patients who did not consent to participate.

Knee Laxity Assessment Under General Anesthesia

Before ACL reconstruction and with the patient under general anesthesia, a physical examination for knee laxity parameters was performed by the senior surgeon (A.F.), including Lachman test, pivot-shift test, and varus and valgus stress at 0° and 30° of knee flexion. A standardized pivot-shift test was performed. Patients were positioned supine on the examination table with the hip passively positioned at 30° of flexion and 15° of abduction. From a starting position of full extension, the knee was flexed to 40° while subjected to valgus stress and internal rotation.[33,40] The magnitude of the pivot shift was graded in accordance with the subjective feel of the reduction as the subluxated tibia reduced during knee flexion. The pivot-shift test was graded according to the classification of the International Knee Documentation Committee (IKDC): grade 0 (normal), grade 1 (glide), grade 2 (clunk), or grade 3 (locked subluxation).[2] Patients who had a positive valgus stress test result underwent a fluoroscopic evaluation of the severity of MCL injury at 30° of flexion. MCL injury was classified according to Hughston et al[9]: grade I, medial opening between 0 and 5 mm; grade II, medial opening between 5 and 10 mm; grade III, medial opening >10 mm. Patients with medial opening >10 mm underwent MCL repair by direct suture retensioning of the torn and stretched ligament with absorbable stitches.

Lateral Exploration and Repair of Anterolateral Structures

All patients underwent an open lateral exploration and evaluation of injury to the anterolateral structures (ALS) ± repair in the same manner as described by Ferretti et al[1] (Figure 1):

Type I: multilevel rupture with individual layers torn at different levels, with macroscopic hemorrhage involving the area of the anterolateral ligament (ALL) and extending to the anterolateral (AL) capsule.
Type II: multilevel rupture with individual layers torn at different levels, with macroscopic hemorrhage extending from the area of the ALL and capsule to the posterolateral capsule.
Type III: complete transverse tear involving the area of the ALL near its insertion to the lateral tibial plateau, distal to the lateral meniscus.
Type IV: bony avulsion (Segond fracture).

AL and posterolateral capsule areas were defined per Hughston et al's definition of 3 distinct portions of the lateral capsuloligamentous tissues: anterior and middle (AL) and posterior (posterolateral).[9] The lateral compartment was approached by a 5 to 7 mm–long hockey stick incision extending proximally from the Gerdy tubercle. The fascia lata was longitudinally split to expose the ALS. Injuries of the ALS (including iliotibial band) were photographed and recorded according to the classification proposed by Ferretti et al.[1] If an injury was present, a repair was performed with 3 or 4 parallel stitches with square knots (No. 2 Vicryl; Ethicon) with the knee at 90° of flexion and neutral rotation.

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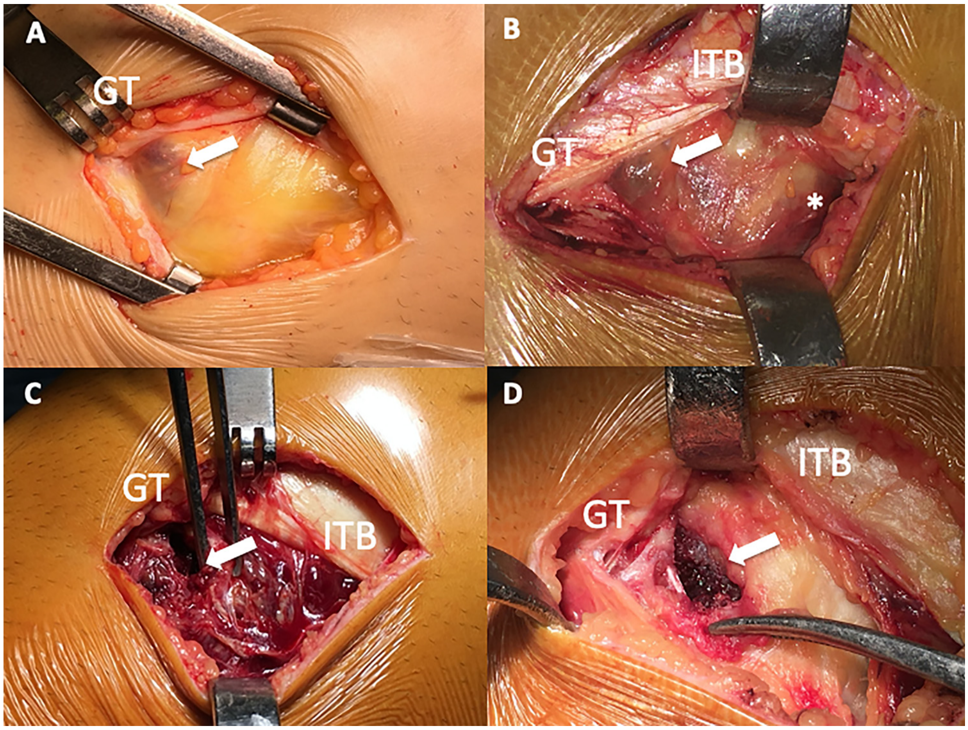

Figure 1. The lateral compartment is exposed deep to the ITB. (A) Type I lesion: multilevel AL capsular lesion (white arrow). (B) Type II lesion: multilevel rupture from AL capsule (white arrow) to posterolateral capsule (*). (C) Type III lesion: AL capsular complete tear (white arrow). (D) Type IV lesion: Segond fracture (white arrow). AL, anterolateral; GT, Gerdy tubercle; ITB, iliotibial band.

ACL Reconstruction

ACL reconstruction was performed with an outside-in technique and doubled semitendinosus and gracilis tendon autografts. The tibial tunnel was drilled over a guide wire that was placed in the anatomic tibial ACL attachment site using a tibial drill guide (Arthrex) set at 60° to 65° with a standard anterograde drill. On the femoral side, a 25-mm bone socket was drilled via an outside-in technique and using a femoral guide with drill sleeve set at approximately 100° to 110° and a Flipcutter retrodrill (Arthrex). The graft was then passed and fixed with an adjustable-loop cortical button on the femur (TightRope-RT; Arthrex) and an absorbable interference screw (Deltascrew; Arthrex), sized 1 mm greater than the graft diameter, on the tibia.

Details regarding patient and injury characteristics (including all associated lesions) were recorded. Articular cartilage lesions were classified according to the Outerbridge classification, as described by Noyes and Stabler[21]:

Grade 0: normal
Grade I: cartilage with softening and swelling
Grade II: a partial-thickness defect with fissures on the surface that do not reach subchondral bone or exceed 1.5 cm in diameter
Grade III: fissuring to the level of subchondral bone in an area with a diameter >1.5 cm
Grade IV: exposed subchondral bone

Evaluation of Osseous Parameters

The tibial slope was evaluated with MRI as described by Hudek et al[8] (Figure 2). The central sagittal image was identified and selected in which the tibial attachment of the posterior cruciate ligament, the intercondylar eminence, and the anterior and posterior tibial cortices appear in a concave shape. Computer software (Horos software, v 3.3.5), which provided an infinite number of diameters and free positioning, was used to place 2 circles on the selected image at the level of the proximal tibia. All measurements were positioned as an overlay and remained in a fixed position on the complete image series. The proximal circle was placed so that it was in contact with the anterior, posterior, and most cranial tibial cortex, and the distal circle was placed so that it was in contact with the anterior and posterior cortical borders. In cases with undefined borders between the cortex and the medullary canal, the middle of the transition zone between a definitive black cortex and a light gray medullary canal was chosen. To set a standardized relative distance between the circles, the center of the caudal circle was arranged on the circumference of the proximal circle. The MRI longitudinal axis was defined by a line that connected the centers of these 2 circles. Next, the MRI scan showing the mediolateral center of the medial plateau was identified. On this image, a tangent to the medial plateau was drawn connecting the upper edges of the superoanterior and posterior cortex edges.

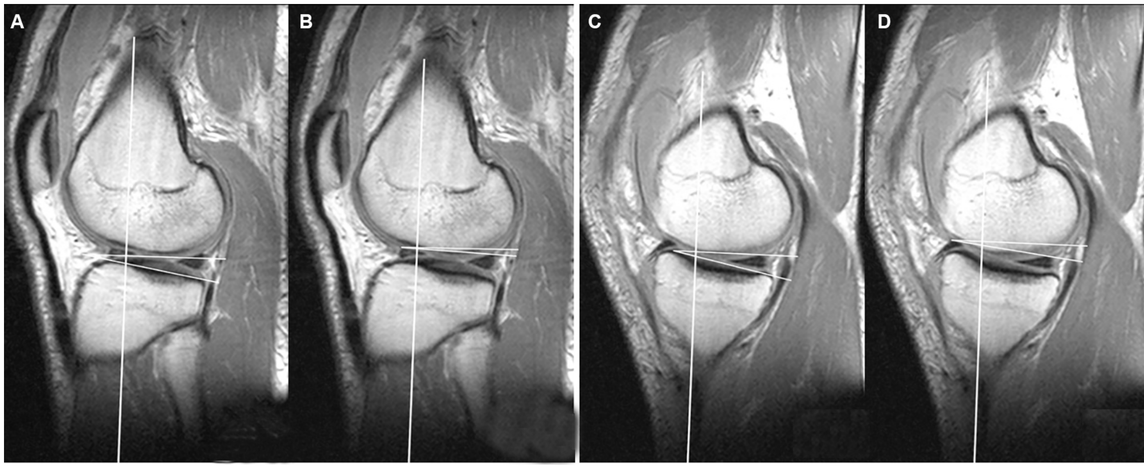

Figure 2. Measurement of bony tibial slope and meniscal tibial slope on magnetic resonance imaging as described by Hudek et al.[8] The figure shows sagittal magnetic resonance images at the mediolateral center of the medial plateau and lateral plateau. (A) Lateral bony tibial slope. (B) Lateral meniscal tibial slope. (C) Medial bony tibial slope. (D) Medial meniscal slope.

The slope of the medial plateau was defined by the orthogonal to the MRI longitudinal axis and the tangent to the medial plateau. The lateral plateau tibial slope was measured accordingly in the mediolateral center of the lateral plateau by a tangent to the upper part between the superoanterior and posterior cortices.

The meniscal slope was evaluated according to the modification of the aforementioned technique, also described by Hudek et al.[8] A tangent to the superior edge of the meniscosynovial border of the anterior and posterior meniscus on the sagittal plane was chosen instead of the tibial plateau cortices.

Femoral condylar morphology was evaluated with MRI according to Grassi et al.[4] First, the femoral axis was identified with the tool provided by the Horos software. The axis tool was fitted to the anterior and posterior cortex of the distal femoral diaphysis at the central sagittal image and reported in all sagittal slices of the MRI. After identification of the most posterior portion of the femoral condyle's subchondral bone with an axial reference, a line overlapping the femoral axis was drawn (line A). The line connecting line A with the most posterior cortex was defined as the depth of the femoral condyle (line B). Then a line parallel to line B was drawn, connecting the femoral axis (line A) to the most distal point of the femoral condyle (line C). The distance between line C and line B was measured as the height of the femoral condyle. The lateral and medial femoral condyle ratios were calculated by height/depth measurements. Values toward 1 approximated a spherical shape, while values toward 0 approximated a more elliptical shape.

Sample Size Calculation

An online sample size calculator for linear regression studies was utilized (statskingdom.com). Based on $\alpha = .05$, $f^2 = 0.15$, and 20 variables evaluated for potential predictive value, a minimum of 157 patients were required to achieve an adequately powered study (0.8).

Statistical Analyses

All calculations were performed with SAS for Windows (v 9.4; SAS Institute Inc), with the level of statistical significance set at $P < .05$. Descriptive data analysis was conducted depending on the nature of the considered criteria. For quantitative data, this included the number of observed values (and missing, if any), mean, standard deviation, median, first and third quartiles, and minimum and maximum. For qualitative data, this included the number of observed values (and missing, if any) and the number and percentage of patients per category.

The characteristics of the population were described after patients were grouped into grade 3 pivot shift and low-grade pivot shift (grades 1 and 2). A multivariate logistic regression with penalized maximum likelihood (Firth logistic regression) was used to identified risk factors associated with grade 3 pivot shift. Factors initially considered were those selected as statistically significant at the 25% threshold or those of previously reported clinical interest. A stepwise descending strategy was applied from the initial full model to determine the most parsimonious one, removing step-by-step all the nonstatistically significant parameters and keeping only the clinically relevant parameters and confounding factors (if any).

RESULTS

Two hundred consecutive patients were prospectively enrolled to the study. The mean ± SD age of the population was 28.3 ± 9.8 years. Additional sociodemographic characteristics are detailed in Table 1.

TABLE 1
Sociodemographic Characteristics of the Study Populations and Injury Mechanisms[a]

	Total (N = 200)	Pivot Shift	
		Grades 1 and 2 (n = 165)	Grade 3 (n = 35)
Age, y			
Mean (SD)	28.3 (9.8)	28.0 (9.0)	29.6 (13.0)
Median (Q1; Q3)	27 (21; 33)	27 (21; 32)	24 (20; 40)
Min; max	13; 68	13; 58	17; 68
Sex, No. (%)			
Female	65 (32.5)	53 (32.1)	12 (34.3)
Male	135 (67.5)	112 (67.9)	23 (65.7)
Body mass index, kg/m^2			
Mean (SD)	22.5 (2.4)	22.6 (2.4)	22.4 (2.4)
Median (Q1; Q3)	23 (21; 25)	23 (21; 25)	23 (20; 25)
Min; max	18; 27	18; 27	19; 27
Sport, No. (%)			
Basket ball	19 (9.5)	13 (7.9)	6 (17.1)
Football	82 (41.0)	74 (44.8)	8 (22.9)
Gymnastics	5 (2.5)	5 (3.0)	
Handball	6 (3 0)	6 (3.6)	
Rugby	12 (6.0)	11 (6.7)	1 (2.9)
Skiing	34 (17.0)	26 (15.8)	8 (22.9)
Volley ball	42 (21.0)	30 (18.2)	12 (34.3)
Mechanism of injury, No. (%)			
Contact	43 (21.5)	39 (23.6)	4 (11.4)
No contact	157 (78.5)	126 (76.4)	31 (88.6)

[a]max, maximum; min, minimum; Q1, first quartile; Q3, third quartile.

Thirty-five (17.5%) patients had a grade 3 pivot shift, and 165 (82.5%) had a low-grade pivot shift. The rate of associated injuries (ALS, MCL, meniscal, and cartilage injuries) in each pivot-shift category are detailed in Table 2. Radiologically determined osseous parameters are similarly reported in Table 3.

Univariate analysis demonstrated that injury to the ALS was the only significant risk factor for grade 3 pivot shift (Table 4). Variables were included in the initial multivariate model only if they were significantly associated with the dependent variable at a significance level of P = .25 or if the prognostic factors had been established in the literature. Therefore, sports type, ALS lesion, mechanism of injury, MCL injury, and lateral meniscal slope were included in the initial multivariate model. The final model was the result of a manual backward stepwise selection of variables, with a significance level of P = .05. Multivariate analysis (Table 5) identified that ALS injury was the only significant risk factor associated with grade 3 pivot shift.

DISCUSSION

The main findings of this study were that injury to the ALS was the most important risk factor for a grade 3 pivot shift and that other previously reported potentially important factors were not significant in univariate analysis or when osseous and soft tissue parameters were comprehensively accounted for in multivariate analyses.

Injury to the ALS has been identified as a risk factor for a high-grade pivot shift.[30] Song et al[29] reported that patients with high-grade pivot shift (which they defined as IKDC grades 2 and 3) had a significantly higher incidence of ALS injury and, in a separate study,[28] that an abnormal ALS on preoperative MRI conferred an increased risk of grade 3 pivot shift (vs grade 1: odds ratio, 8.28 [95% CI, 1.71-117.14]; vs grade 2: odds ratio, 4.96 [95% CI, 1.07-28.75]). These findings demonstrate an important role for the ALS in control of the pivot shift. They are also consistent with numerous laboratory sectioning studies that showed increased internal rotation and axial plane translation during the pivot shift in knees with combined ACL and ALS injury, as compared with isolated ACL injury.[3,13,25,26,31,36,38] Specifically, Monaco et al[13] demonstrated that isolated sectioning of the ACL does not typically produce grade 3 pivot shift but that concomitant sectioning of the ALS results in grade 3 pivot shift in the majority of specimens. Furthermore, the role of the ALS in controlling the pivot shift has clinically been demonstrated by the fact that repair of an ALS lesion can abolish the pivot shift, even before ACL reconstruction.[15] However, there has been controversy regarding this role for the ALS, and some authors have not found it to be important in kinematic control of the knee, although the design of these studies has been criticized by some.[6,20,27] The current study confirms that injury to the ALS is a significant risk factor for grade 3 pivot shift. It should be noted that every patient who had a grade 3 pivot shift had an ALS injury. Although previous authors have suggested that

TABLE 2
Rate of Associated Injuries Identified, Stratified by Grade 1-2 and 3 Pivot Shift[a]

		Pivot Shift	
	Total (N = 200)	Grades 1 and 2 (n = 165)	Grade 3 (n = 35)
ALS lesion			
No lesion	26 (13.0)	26 (15.8)	
Incomplete tear AL capsule	34 (17.0)	32 (19.4)	2 (5.7)
Incomplete tear AL and PL capsule	66 (33.0)	45 (27.3)	21 (60.0)
Complete tear	58 (29.0)	50 (30.3)	8 (22.9)
Segond fracture	16 (8.0)	12 (7.3)	4 (11.4)
ALS lesion			
Yes	174 (87.0)	139 (84.2)	35 (100)
No	26 (13.0)	26 (15.8)	
MCL, mm			
0	174 (87.0)	146 (88.5)	28 (80.0)
>0-5	16 (8.0)	11 (6.7)	5 (14.3)
>5-10	7 (3.5)	6 (3.6)	1 (2.9)
>10	3 (1.5)	2 (1.2)	1 (2.9)
MCL			
Yes	26 (13.0)	19 (11.5)	7 (20.0)
No	174 (87.0)	146 (88.5)	28 (80.0)
Outerbridge			
0	191 (95.5)	157 (95.2)	34 (97.1)
Grade 1 MFC	7 (3.5)	6 (3.6)	1 (2.9)
Grade 2 MFC	1 (0.5)	1 (0.6)	
Grade 2 LFC	1 (0.5)	1 (0.6)	
Outerbridge			
Yes	9 (4.5)	8 (4.8)	1 (2.9)
No	191 (95.5)	157 (95.2)	34 (97.1)
Medial meniscal tears			
No lesion	166 (83)	138 (83.6)	28 (80.0)
Bucket handle	3 (1.5)	3 (1.8)	
Longitudinal anterior horn	5 (2.5)	4 (2.4)	1 (2.9)
Longitudinal posterior horn	21 (10.5)	16 (9.7)	5 (14.3)
Radial lesion	5 (2.5)	4 (2.4)	1 (2.9)
Ramp lesion	19 (9.5)	19 (11.5)	
Medial meniscal tears			
Yes	34 (17)	27 (16)	7 (20.0)
No	166 (78)	138 (84)	28 (80.0)
Lateral meniscal tears			
No lesion	154 (77.0)	128 (77.6)	26 (74.2)
Flap handle	3 (1.5)	2 (1.2)	1 (2.9)
Longitudinal anterior horn	15 (7.5)	12 (7.3)	3 (8.6)
Longitudinal posterior horn	4 (2.0)	2 (1.2)	2 (5.7)
Radial lesion	24 (12.0)	21 (12.7)	3 (8.6)
Root lesion	14 (7.0)	13 (7.9)	1 (2.9)
Lateral meniscal tears			
Yes	46 (23)	37 (22)	9 (25.8)
No	154 (77)	128 (78)	26 (74.2)
Medial and lateral meniscal tears			
Yes	5 (2.5)	5 (3.0)	
No	195 (97.5)	160 (97.0)	35 (100.0)

[a]Values are presented as No. (%). AL, anterolateral; ALS, anterolateral structures; LFC, lateral femoral condyle; MCL, medial collateral ligament; MFC, medial femoral condyle; PL, posterolateral.

there are other important risk factors for grade 3 pivot shift, this did not hold true in the current study. It is likely that this finding is multifactorial. A major advantage of the current study was that only acute cases of ACL rupture were included. In this way, any possible changes occurring as a result of knee dysfunction related to chronic instability and repeated episodes of giving way were excluded. Therefore, the surgical anatomy reported in the present study truly refers to the actual pattern of anatomic factors associated with the pivot-shift phenomenon. An additional

TABLE 3
Radiologically Determined Osseous Parameters Stratified by Pivot-Shift Group[a]

		Pivot Shift	
	Total (N = 200)	Grades 1 and 2 (n = 165)	Grade 3 (n = 35)
Slope meniscal lateral			
Mean (SD)	5.5 (2.6)	5.4 (2.5)	5.8 (2.9)
Median (Q1; Q3)	5 (4; 8)	5 (4; 8)	6 (3; 8)
Min; max	0; 12	0; 12	1; 11
Slope bony lateral			
Mean (SD)	8.6 (3.9)	8.5 (3.8)	8.8 (4.1)
Median (Q1; Q3)	9 (7; 11)	9 (7; 11)	8 (7; 11)
Min; max	–2; 24	–2; 20	0; 24
Slope meniscal medial			
Mean (SD)	5.5 (3.3)	5.5 (3.3)	5.4 (3.3)
Median (Q1; Q3)	5 (3; 8)	5 (3; 8)	5 (3; 9)
Min; max	–2; 16	–2; 16	–1; 11
Slope bony medial			
Mean (SD)	8.1 (3.2)	8.1 (3.2)	7.9 (3.5)
Median (Q1; Q3)	8 (6; 10)	8 (6; 10)	8 (6; 11)
Min; max	1; 16	1; 16	1; 16
Medial condylar depth			
Mean (SD)	4.1 (0.4)	4.1 (0.4)	4.1 (0.4)
Median (Q1; Q3)	4 (4; 4)	4 (4; 4)	4 (4; 4)
Min; max	3; 6	3; 6	3; 6
Medial condylar height			
Mean (SD)	2.2 (0.4)	2.2 (0.4)	2.2 (0.4)
Median (Q1; Q3)	2 (2; 2)	2 (2; 2)	2 (2; 2)
Min; max	2; 4	2; 3	2; 4
Lateral condylar depth			
Mean (SD)	4.0 (0.4)	4.0 (0.3)	3.9 (0.4)
Lateral condylar height			
Mean (SD)	2.0 (0.4)	2.0 (0.4)	2.1 (0.6)
Median (Q1; Q3)	2 (2; 2)	2 (2; 2)	2 (2; 2)
Min; max	1; 4	1; 3	1; 4
Medial ratio			
Mean (SD)	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)
Median (Q1; Q3)	1 (0; 1)	1 (0; 1)	1 (0; 1)
Min; max	0; 1	0; 1	0; 1
Lateral ratio			
Mean (SD)	0.5 (0.1)	0.5 (0.1)	0.6 (0.3)
Median (Q1; Q3)	0 (0; 1)	1 (0; 1)	0 (0; 1)
Min; max	0; 2	0; 1	0; 2

[a]max, maximum; min, minimum; Q1, first quartile; Q3, third quartile.

important aspect that explains the differences in the findings of the current study as compared with previous studies includes their use of typically small study populations, resulting in underpowering. In fact, in 2016, Magnussen et al[12] highlighted that small study sizes were an important limitation of all previous studies. The authors addressed this issue by using a study population of >2000 patients. It was demonstrated that patients aged <20 years and those with generalized ligamentous laxity, chronic injuries, or meniscal tears were all at significantly increased risk of grade 3 pivot shift. However, confidence in these findings has been low given the limitation of Magnussen et al and many other studies to include a comprehensive evaluation of soft tissue and osseous risk factors. Of particular note, the ALS was not evaluated. Furthermore, the study utilized multiple observers, and this is an important limitation because it is recognized that the interobserver reliability of the pivot-shift test is highly variable.

In the current study, none of the radiological and/or osseous parameters studied were identified as significant risk factors for grade 3 pivot shift. This included medial and lateral tibial and meniscal slopes. These findings are in keeping with those of Grassi et al,[5] who reported that osseous anatomy had little influence on determining the pivot shift. However, like many previous studies, the strength of evidence was limited by sample size (n = 42). In contrast, Rahnemai-Azar et al[24] (n = 53) reported that lateral tibial plateau slope was significantly associated with the amount of rotatory knee laxity measured by quantitative pivot shift; however, the study did not account for concomitant secondary restraint lesions, and it used an

TABLE 4
Univariate Analysis of Potential Risk Factors for Grade 3 Pivot Shift (N = 200)

	Odds Ratio (95% CI)	*P* Value[a]
Sex: female vs male	1.12 (0.51-2.36)	.773
Age	1.02 (0.98-1.05)	.359
Body mass index	0.98 (0.84-1.14)	.777
Sport: nonpivoting sport vs sport pivot	1.63 (0.65-3.79)	.287
ALS lesion: yes vs no	13.49 (1.80-1725.53)	**.005**
Mechanism of injury: contact vs no contact	0.46 (0.14-1.20)	.117
Medial collateral ligament: yes vs no	1.98 (0.74-4.88)	.167
Medial meniscal tears: yes vs no	0.68 (0.26-1.55)	.368
Lateral meniscal tears: yes vs no	0.94 (0.41-2.03)	.882
Medial and lateral meniscal tears: yes vs no	2.43 (0.27-322.12)	.501
Slope meniscal lateral	1.06 (0.93-1.22)	.380
Slope bone lateral	0.99 (0.89-1.11)	.719
Slope meniscal medial	1.02 (0.93-1.12)	.870
Slope bone medial	0.98 (0.88-1.10)	.757
Medial condylar depth	1.18 (0.49-2.63)	.703
Medial condylar height	1.04 (0.39-2.68)	.934
Lateral condylar depth	0.45 (0.17-1.19)	.106
Lateral condylar height	1.45 (0.65-3.18)	.354
Medial ratio	0.54 (0.01-45.72)	.782
Lateral ratio	6.57 (0.89-88.62)	.065
Outerbridge: yes vs no	0.81 (0.08-3.76)	.807

[a]Boldface indicates statistical significance ($P < .05$). ALS, anterolateral structures.

TABLE 5
Multivariate Analysis of Potential Risk Factors for Grade 3 Pivot Shift (N = 200)

	Odds Ratio (95% CI)	*P* Value[a]
ALS lesion: yes vs no	13.49 (1.80-1725.53)	**.005**
Mechanism of injury: contact vs no contact	0.44 (0.13-1.20)	.113
Medial collateral ligament: yes vs no	1.95 (0.71-5.03)	.187
Lateral condylar depth	0.66 (0.21-2.11)	.485
Lateral ratio	4.28 (0.40-80.23)	.237
Sport: nonpivoting sport vs sport pivot	1.15 (0.42-2.92)	.768
Slope meniscal lateral	1.07 (0.92-1.24)	.362

[a]Boldface indicates statistical significance ($P < .05$). ALS, anterolateral structures.

uncited artificial cutoff to define high-grade laxity (instead of the widely accepted IKDC grading).

Song et al,[28] in a larger study (n = 90), also reported that the lateral, not medial, tibial slope was a risk factor for grade 3 pivot shift. The strengths of this study included a comprehensive analysis of soft tissue parameters, including the ALS. However, a key difference that may explain the conflicting results is that Song et al[29] utilized MRI to diagnose ALS injury but also grouped pivot-shift grades 2 and 3, whereas the current study evaluated grade 3 separately. The authors identified an ALS injury rate of only 55%. At the time of publication of that study, MRI evaluation of the ALS was associated with low rates of identification of injury in ACL-injured knees.[35,39] However, with advances in MRI evaluation, multiple recent studies[14,17] have demonstrated that the rate of injury is typically closer to 90% in acute ACL-injured knees, and this suggests that the use of MRI by Song et al[29] may have resulted in confounding because of missed diagnoses of ALS injury. The use of lateral exploration in the current study identified a rate of ALS injury of 87%, which is consistent with the rate expected based on contemporary studies.

In a small series (n = 57), Pfeiffer et al[22] reported that the lateral femoral condylar ratio was correlated with lateral compartment translation during the pivot shift, but they did not evaluate IKDC grade or suggest that a large ratio would confer a high-grade pivot shift. The authors excluded patients with concomitant meniscus and ligament injuries, but they did not state that they excluded or accounted for ALS injuries. In contrast, in the current larger study, concomitant injuries were not excluded, but neither lateral nor medial femoral condylar height, depth, or ratios were significantly associated with grade 3 pivot shift in univariate analyses or when other potentially important factors were accounted for in multivariate analyses.

Numerous cadaveric and clinical studies have suggested that meniscal deficiency has an important influence on the pivot shift.[7,10,12,19,28] However, consistent with the findings of the current study, Hoshino et al,[7] in a small clinical study (n = 57), did not find a difference in the clinical grade of pivot shift in knees with and without meniscal tears. However, they did demonstrate that when a quantitative pivot shift was assessed with an electromagnetic measurement system, there was increased tibial acceleration in knees with lateral but not medial meniscal tears. In addition, Katakura et al[10] recently demonstrated that repair of lateral but not medial meniscal tears before ACL reconstruction significantly reduced tibial acceleration during the pivot-shift test, but they did not report the IKDC grade. These studies both suggest that meniscal tears do have an influence on components of the pivot shift, but the actual changes in tibial acceleration are small. This suggests that the effect of meniscal tears on rotatory stability may not be large enough to alter the IKDC grade or that IKDC grading is not sensitive enough to its influence. However, the literature on this topic remains controversial because Song et al[28] (lateral but not medial) and Magnussen et al[12] (medial and lateral) found meniscal tears to be significantly associated with grade 3 pivot shift. It is clear that, based on the limitations of the existing literature on this topic, a definitive conclusion remains elusive with respect to the role of meniscal injuries in determining rotatory laxity, and future studies should seek to address these methodological weaknesses. It should be additionally noted that Hoshino et al highlighted that to have adequate numbers of patients in order to analyze the influence of meniscal tear type and location more precisely, a very large study population is needed.

Limitations

This study had several limitations. First, the IKDC grade was utilized because it is the most frequently used clinical classification of the pivot-shift test. However, it appears that the use of quantitative pivot shift (tibial acceleration) may be more sensitive to change, and its use should be considered in future studies. A further limitation is that the study population—although exceeding the sample size requirement and being considerably larger than the majority of previous publications on this topic—may still have been insufficient to analyze the role of different types of meniscal tear. The inclusion of only knees with acute ACL injuries means that results may not reliably extrapolate to chronic ACL injuries. The use of a single observer for pivot shift may also limit external validity and is a potential source of bias, but this approach was adopted to minimize the effect of the limited interobserver reliability of the pivot-shift test.

CONCLUSION

This comprehensive evaluation of soft tissue and osseous factors has identified that injury to the ALS is the most important risk factor for grade 3 pivot shift in knees with acute ACL injuries.

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