Original Research

Association of Ligamentous Laxity, Male Sex, Chronicity, Meniscal Injury, and Posterior Tibial Slope With a High-Grade Preoperative Pivot Shift

A Post Hoc Analysis of the STABILITY Study

Lachlan M. Batty, MBBS, Andrew Firth, MSc, Gilbert Moatshe, MD, PhD, Dianne M. Bryant, PhD, Mark Heard, MD, Robert G. McCormack, MD, Alex Rezansoff, MD, Devin C. Peterson, MD, Davide Bardana, MD, Peter B. MacDonald, MD, Peter C.M. Verdonk, MD, PhD, Tim Spalding, MBBS, Alan M.J. Getgood,* MD; and STABILITY Study Group

Investigation performed at the Fowler Kennedy Sport Medicine Clinic, Western University, London, Ontario, Canada

Background: A spectrum of anterolateral rotatory laxity exists in anterior cruciate ligament (ACL)–injured knees. Understanding of the factors contributing to a high-grade pivot shift continues to be refined.

Purpose: To investigate factors associated with a high-grade preoperative pivot shift and to evaluate the relationship between this condition and baseline patient-reported outcome measures (PROMs).

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

Methods: A post hoc analysis was performed of 618 patients with ACL deficiency deemed high risk for reinjury. A binary logistic regression model was developed, with high-grade pivot shift as the dependent variable. Age, sex, Beighton score, chronicity of the ACL injury, posterior third medial or lateral meniscal injury, and tibial slope were selected as independent variables. The importance of knee hyperextension as a component of the Beighton score was assessed using receiver operator characteristic curves. Baseline PROMs were compared between patients with and without a high-grade pivot.

Results: Six factors were associated with a high-grade pivot shift: Beighton score (each additional point; odds ratio [OR], 1.17; 95% CI, 1.06-1.30; $P = .002$), male sex (OR, 2.30; 95% CI, 1.28-4.13; $P = .005$), presence of a posterior third medial (OR, 2.55; 95% CI, 1.11-5.84; $P = .03$) or lateral (OR, 1.76; 95% CI, 1.01-3.08; $P = .048$) meniscal injury, tibial slope $>9^\circ$ (OR, 2.35; 95% CI, 1.09-5.07; $P = .03$), and chronicity >6 months (OR, 1.70; 95% CI, 1.00-2.88; $P = .049$). The presence of knee hyperextension improved the diagnostic utility of the Beighton score as a predictor of a high-grade pivot shift. Tibial slope $<9^\circ$ was associated with only a high-grade pivot in the presence of a posterior third medial meniscal injury. Patients with a high-grade pivot shift had higher baseline 4-Item Pain Intensity Measure scores than did those without a high-grade pivot shift (mean ± SD, 11 ± 13 vs 8 ± 14; $P = .04$); however, there was no difference between groups in baseline International Knee Documentation Committee, ACL Quality of Life, Knee injury and Osteoarthritis Outcome Score, or Knee injury and Osteoarthritis Outcome Score subscale scores.

Conclusion: Ligamentous laxity, male sex, posterior third medial or lateral meniscal injury, increased posterior tibial slope, and chronicity were associated with a high-grade pivot shift in this population deemed high risk for repeat ACL injury. The effect of tibial slope may be accentuated by the presence of meniscal injury, supporting the need for meniscal preservation. Baseline PROMs were similar between patients with and without a high-grade pivot shift.

Keywords: anterior cruciate ligament; pivot shift; instability; laxity; knee; hyperextension

In patients with anterior cruciate ligament (ACL) injury, there is a spectrum in the severity of anterolateral rotatory laxity and symptoms of instability. The cause of this variability is multifactorial; however, increasing evidence

The Orthopaedic Journal of Sports Medicine, 9(4), 23259671211000038
DOI: 10.1177/23259671211000038

points to a complex interplay between the degree and characteristics of injury to the ACL,[20,22] injury to secondary knee stabilizers,[5,11,17,32,34] and bony morphologic parameters,[8,36] as well as patient characteristics including soft tissue and neuromuscular profiles.[21,26,45]

The pivot shift is the most commonly used clinical examination technique to evaluate and grade anterolateral rotatory laxity. The preoperative pivot shift has particular clinical importance because increased preoperative pivot-shift severity has been associated with residual postoperative pivot shift after ACL reconstruction.[47,49] Furthermore, a higher preoperative pivot-shift grade has been associated with increased rates of ACL graft revision[27] and failure of attempted nonoperative management.[20] Residual pivot shift after ACL reconstruction has been associated with reduced functional outcome scores[2] and development of early osteoarthritis.[19] For these reasons, identifying factors that influence the preoperative pivot-shift grade is important, and where possible, addressing these factors via an individualized surgical plan may help to improve patient outcomes. An understanding of these factors continues to develop; however, there are conflicting data regarding the role of specific factors, including age,[8,26,42] sex,[23,26,42] ligamentous laxity,[26,45] injury chronicity,[23,26,34,42] tibial slope,[8,42] and medial meniscal pathology,[8,26,42] among others.

In the setting of ACL deficiency, patient-reported outcome measures (PROMs) have been recognized as an important metric in evaluating the success of surgical and nonsurgical interventions. Patient and injury factors have been shown to influence baseline PROMs in the setting of ACL reconstruction.[10,33] However, it is unclear if there is a relationship between severity of anterolateral rotatory laxity as measured using the pivot shift and baseline PROMs. Understanding the effect of a high-grade pivot shift on baseline PROMs is valuable in helping to interpret PROM data and may be helpful in counseling patients regarding prognosis. Baseline PROMs have been shown to influence postoperative PROMs after knee ligament surgery,[28] and it is possible that patients with lower baseline PROM scores may have reduced capacity to achieve the Patient Acceptable Symptom State, a PROM threshold for "feeling well."[31]

The first aim of this investigation was to identify factors associated with a high-grade preoperative pivot shift (International Knee Documentation Committee [IKDC] grade 3) in a cohort of patients undergoing primary ACL reconstruction who were deemed high risk for repeat injury. The second aim was to investigate the effect of a preoperative high-grade pivot shift on baseline PROMs. The hypotheses were that the selected patient and injury factors would be associated with a high-grade pivot shift and that a high-grade pivot shift would be associated with worse baseline PROMs.

METHODS

This study was approved by the appropriate ethical review board at each participating institution. Informed consent was provided by each patient to participate in the trial.

Study Design and Participants

This post hoc multivariable binary logistic regression analysis was based on a multicenter randomized controlled trial investigating outcomes of hamstring ACL reconstruction with or without a lateral extra-articular tenodesis.[12] Inclusion criteria for this trial were ACL deficiency, age between 14 and 25 years, and ≥ 2 of the following factors: participation in competitive pivoting sports, presence of a grade ≥ 2 pivot shift, generalized ligamentous laxity (Beighton score ≥ 4),[6] and genu recurvatum $>10^\circ$ in either knee. Exclusion criteria were previous ACL reconstruction on either knee, multiligament knee injury (≥ 2 ligaments requiring surgical treatment), symptomatic articular cartilage defect requiring treatment other than debridement, $>3^\circ$ of asymmetric varus, unable or unwilling to be followed up for 2 years postoperatively, and skeletal immaturity. Enrollment of patients occurred between January 2014 and March 2017.

Dependent Variable: Pivot Shift

In the current study, the dependent variable was the presence of a high-grade pivot shift. During the initial trial, pivot-shift testing was performed in a standardized fashion by the operating surgeon. To address the limitations of assessing the pivot shift in the awake patient, initial assessment was conducted in clinic where patients were flagged as potentially meeting inclusion criteria for the study. On the day of surgery, the pivot shift was repeated with the patient under anesthesia, and if the patient met inclusion criteria based on the updated information, he or she was formally enrolled in the study and assigned a

*Address correspondence to Alan M.J. Getgood, MD, Fowler Kennedy Sport Medicine Clinic, 3 M Centre, Western University, London, ON N6A 3K7, Canada (email: alan.getgood@uwo.ca) (Twitter: @FKSMC_Getgood).

All authors are listed in the Authors section at the end of this article.

Final revision submitted January 25, 2021; accepted January 28, 2021.

One or more of the authors has declared the following potential conflict of interest or source of funding: This study was funded by an ISAKOS/OREF grant (2014; International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine/Orthopaedic Research and Education Foundation). R.G.M. has received speaking fees from Bioventus, Pendopharm, Sanofi, and Smith & Nephew. T.S. has received consulting fees from Conmed and speaking fees from Conmed, Joint Operations, and Smith & Nephew. P.C.M.V. has received consulting fees from Conmed and speaking fees from Conmed and Smith & Nephew. A.M.J.G. has received consulting fees from Olympus, Ossur, and Smith & Nephew and royalties from Graymont and Smith & Nephew. L.A.H. has received consulting fees and speaking fees from Conmed. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the University of Western Ontario (file No. 104524).

group. Of note, in the intial trial some patients met inclusion criteria independent of pivot-shift grade, which is why some patients had a lower-grade pivot shift. All surgeons in this study were familiar with the IKDC pivot-shift grading system. The pivot shift was graded as equal (grade 0), a glide (grade 1), a clunk (grade 2), or gross reduction (grade 3).[15] A high-grade pivot was defined as IKDC grade 3.

Predictive Variables

Of the 618 patients in the total study cohort, 73 (11.8%) had a high-grade pivot shift. To minimize the chance of overfitting in the planned binary logistic regression model,[3] 7 independent variables were selected equating to approximately 10 events per variable: age, sex, Beighton score, posterior third medial meniscal tear, posterior third lateral meniscal tear, chronicity of the ACL injury, and tibial slope. These predictive variables were based on a review of the literature and previous similar investigations.[8,26,42]

Patients completed a questionnaire preoperatively that included demographic and injury data, and they underwent a clinical examination by a trained assessor. The Beighton score is an ordinal variable scored between 0 and 9 that measures ligamentous laxity in multiple joints, including knee hyperextension.[6] This was recorded in the awake patient as part of the eligibility screening for the trial. The knee hyperextension component of the Beighton score was assessed again with the patient under anesthesia, and this was the data point used for analysis. Knee hyperextension was considered present if there was passive knee extension beyond 10° from neutral, as measured using a goniometer in either the operative or contralateral knee while the patient lay supine. Chronicity of the ACL injury was calculated as the amount of time between the date of injury and date of surgery. Meniscal tearing was assessed arthroscopically at the time of ACL reconstruction and considered either present or absent in the posterior third of the medial or lateral meniscus. Posterior third meniscal injuries (including posterior meniscus root and ramp injuries) were included for the analysis, as these were thought to be the most clinically important in terms of preventing anterior tibial translation and internal rotation.[1,13,40] Deficiency of the posterior third of the meniscus from a previous partial meniscectomy before ACL injury was classified as a tear for the purpose of this study. Bucket-handle tears were excluded, as they can limit the knee's ability to glide, a prerequisite to perform the pivot shift. Tibial slope was measured on a true lateral radiograph by a fellowship-trained sports medicine surgeon (G.M.). The medial tibial slope was measured per the technique described by Webb et al.[48] Using the picture archiving and communications system, circles touching the anterior and posterior tibial cortex were placed 10 and 20 cm below the joint line on a true lateral knee radiograph or at a minimum 5 and 15 cm if there was an inadequate field of view (Figure 1). The longitudinal axis of the tibia was defined as a line passing through the center of each circle. Another line was drawn from the most anterior to most posterior point of the articular surface of the medial tibial plateau. The more acute angle formed by the intersection of these 2 lines was measured. The tibial slope was defined as 90° minus this angle.

Figure 1. Tibial slope measurement technique. A line passing through the middle of the 2 circles is defined as the longitudinal axis of the tibia. Another line is drawn from the most anterior to the most posterior point of the medial tibial plateau. The tibial slope is calculated as 90° minus the acute angle formed by these 2 lines; in this patient, it is 7.1°.

Patient-Reported Outcome Measures

PROMs included the 4-Item Pain Intensity Measure (P4), ACL Quality of Life (ACL-QOL) questionnaire, IKDC, and Knee injury and Osteoarthritis Outcome Score (KOOS). The P4 consists of 4 items that address pain intensity in the morning, afternoon, and evening and with activity over the past 2 days.[43,44] Each item is scored on a numerical rating scale of 0 to 10; therefore, the total P4 score can vary from 0 (no pain) to 40 (highest possible pain level). The ACL-QOL is a disease-specific scale measuring quality of life that consists of 5 domains: physical symptoms, occupational concerns, recreational activities, lifestyle, and social and emotional aspects.[30] The subjective IKDC score is an 18-item region-specific, patient-reported questionnaire containing the domains of symptoms, function, and sports activities.[16,18] The KOOS[37,38] is a 42-item knee-specific questionnaire with 5 separately reported domains: Pain, other Symptoms, function in Activities of Daily Living, function in Sports/Recreation, and knee-related Quality of Life. Domain scores represent the mean of all items in the domain, standardized to a score between 0 and 100 (best). These questionnaires ask participants to provide answers based on the previous 2 days (P4), current status (ACL-

QOL), the previous 2 weeks (KOOS), and the previous 4 weeks (IKDC). Patients who had their baseline PROMs recorded within 3 months of ACL rupture were excluded to minimize the effect of recovery from the acute injury on the score.

Statistical Analysis

Summary statistics are presented, including means and SDs for continuous variables and proportions for categorical variables. A multivariable binary logistic regression model was developed with high-grade pivot as the dependent variable and the 7 predictors as independent variables. Linearity of predictors and the log odds was assessed visually using LOWESS curves (locally weighted scatterplot smoothing). ACL injury chronicity and tibial slope violated the assumption of linearity. Chronicity of ACL injury was dichotomized at 6 months, consistent with previous investigations[33] in terms of defining "chronic" and with a threshold previously associated with higher-grade rotatory laxity.[26] Tibial slope was dichotomized at 9°, a threshold shown to be associated with higher-grade rotatory laxity for a hypothesis-driven cut point.[36] Nine degrees was also correlated with a data-driven cut point in our data set, with a transition noted at this point. Predictors were then entered into the model, with manual removal of any predictor with a P value >.20 until the simplest model remained.[3] We checked for interaction terms in the model and tested for multicollinearity among predictors, planning to remove those with variance inflation factor >10.[14] Regression diagnostics were performed to identify outliers and influential points by using the Hosmer-Lemeshow test to evaluate goodness of fit and by calculating the area under the receiver operating characteristic (ROC) curve to assess model fit. Patients with missing data were excluded from analysis.

After the development of this model, a post hoc exploratory analysis was performed to assess the clinical importance of knee hyperextension as a component of the Beighton score. We split our sample into those patients with and without knee hyperextension in either knee, and we used our model to predict whether patients had high-grade pivot by developing ROC curves. Furthermore, knee hyperextension in either knee was substituted into the original model as a surrogate for Beighton score, and ROC curves were developed.

For baseline PROMs, means and SEs were calculated for the high- and low-grade pivot groups. We used the Welch t test of unequal variance to compare normally distributed outcomes between groups and the nonparametric Mann-Whitney U test to compare medians and distributions for skewed outcomes. Statistical significance was set at $P < .05$. All analyses were performed using Stata Version 15.1 (StataCorp LLC).

RESULTS

A total of 1033 potential participants were screened: 367 were ineligible and 48 declined participation, leaving 618 enrolled in the trial. Patient characteristics are summarized in Table 1.

TABLE 1
Patient Characteristics

	Mean ± SD or No. (%)
Age, y	18.9 ± 3.2
Male sex	299 (48.3)
Time between injury and surgery, mo	8.8 ± 14.0
Tear chronicity >6 mo	273 (44.2)
Beighton score	3.1 ± 2.7[a]
Knee hyperextension	210 (34.0)
Contact injury	128 (20.7)
Tibial slope, deg[b]	9.0 ± 2.7
Pivot-shift grade[c]	
0	18 (2.95)
1	59 (9.67)
2	460 (75.41)
3	73 (11.97)
Medial meniscal injury	294 (47.6)
Ramp injury	9 (1.5)
Posterior root injury	8 (1.2)
Posterior one-third	240 (38.9)
Bucket-handle	43 (3.9)
Lateral meniscal injury	292 (47.2)
Posterior root injury	41 (7.1)
Posterior one-third	152 (24.6)
Bucket-handle	24 (3.9)

[a]Median, 3 (interquartile range, 5).
[b]Tibial slope data were available for 549 patients.
[c]Missing for 8 patients.

Predictors of a High-Grade Pivot Shift

A total of 548 patients were included in the regression analysis: 62 (10.0%) were excluded for missing tibial slope measurements, 1 (<0.1%) lacked a baseline pivot-shift grade, and 7 (1.1%) did not have tibial slope and baseline pivot-shift measurements. There was an interaction between tibial slope and posterior third medial meniscal tears, and this interaction term was included in the model. There was no evidence of multicollinearity (mean variance inflation factor <1.2), and all variables had a P value <.20; therefore, all were included in the final model. Six factors were significantly associated with a high-grade pivot shift in the binary logistic regression model (Table 2). For each unit increase in the Beighton score, there was 17% higher odds of having a high-grade pivot shift. Male sex was associated with 2.3-times (95% CI, 1.3-4.1) higher odds of a high-grade pivot shift. The presence of a posterior third medial meniscal tear was associated with 2.6-times (95% CI, 1.1-5.8) higher odds of a high-grade pivot shift, and a posterior third lateral meniscal tear was associated with 1.8-times (95% CI, 1.0-3.1) higher odds. Tibial slope >9° was associated with 2.4-times (95% CI, 1.1-5.1) higher odds of a high-grade pivot shift. ACL tear chronicity >6 months was associated with 1.7-times (95% CI, 1.0-2.9) higher odds of a high-grade pivot shift. Two potential outliers were identified; however, removing these points had

TABLE 2
Binary Logistic Regression Model: Predictors of a High-Grade Pivot Shift[a]

Predictor	Odds Ratio (95% CI)	*P* Value
Age	0.94 (0.86-1.03)	.19
Male sex	2.30 (1.28-4.13)	.005
Beighton score	1.17 (1.06-1.30)	.002
Chronicity >6 mo	1.70 (1.00-2.88)	.049
PTMMT	2.55 (1.11-5.84)	.03
Tibial slope >9°	2.35 (1.09-5.07)	.03
Posterior third lateral meniscal tear	1.76 (1.01-3.08)	.048
Tibial slope × PTMMT (interaction)	0.43 (0.15-1.27)	.13

[a]PTMMT, posterior third medial meniscal tear.

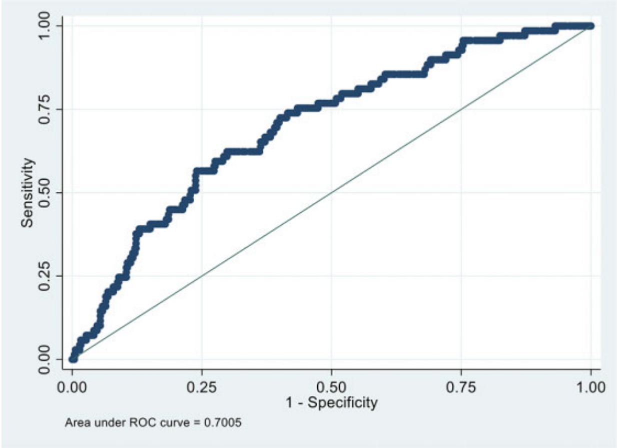

Figure 2. Receiver operating characteristic (ROC) curve for predictors of a high-grade pivot shift. The area under the curve is 0.70.

no effect on the estimated odds ratios (ORs). The Hosmer-Lemeshow test was not significant ($\chi^2 = 2.49$; $P = .96$), and the area under the ROC curve (Figure 2) was 0.70, indicating adequate model fit.

Post Hoc Exploratory Analysis: Knee Hyperextension

In terms of the post hoc exploratory analysis, 193 patients (35.2%) had knee hyperextension present in 1 or both knees as part of their Beighton score, and 355 (64.8%) did not. Of the 548 patients, 511 (93.2%) had the same hyperextension score (yes/no) between the operative and contralateral sides. Of the 37 patients (6.8%) with different values between knees, 33 had hyperextension on the contralateral but not injured side, and 4 had hyperextension on the injured but not contralateral side. Our model better classified patients and predicted a high-grade pivot shift when knee hyperextension was present (area under the curve, 0.75) versus not present (area under the curve, 0.65) (Figure 3). When the presence or absence of knee hyperextension was substituted for Beighton score into the original model, patients with knee hyperextension had 2.30 times the odds of a high-grade pivot ($P = .002$), and the area under the curve was 0.70.

Association Between Preoperative Pivot Shift and Baseline PROMs

There was no difference in mean baseline IKDC, ACL-QOL, KOOS, or KOOS subscale scores between patients who had a high-grade pivot and those who did not. There was a difference between these groups in terms of the baseline mean P4 score, with higher pain scores seen in the high-grade pivot-shift group (Table 3).

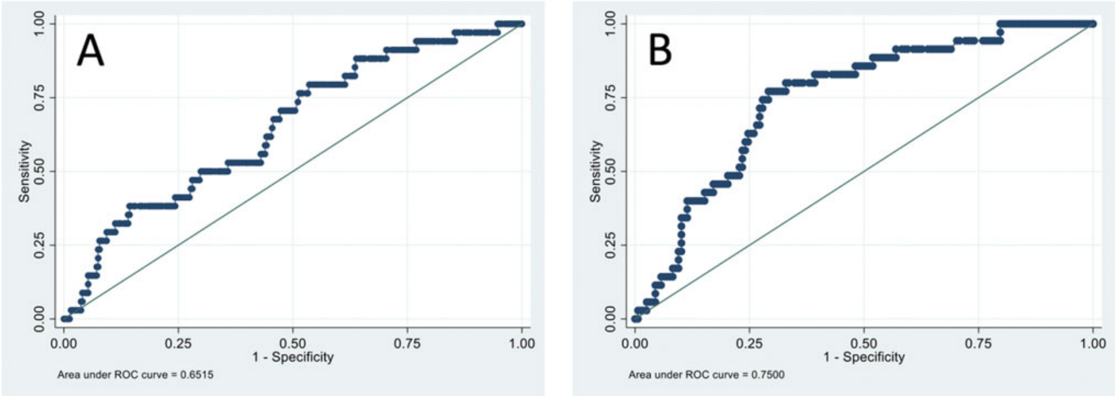

Figure 3. Receiver operating characteristic (ROC) curves for predictors of a high-grade pivot shift. Models predicting high-grade preoperative pivot: (A) 355 patients without knee hyperextension as part of their Beighton scores (area under the curve, 0.65) and (B) 193 patients with knee hyperextension as part of their Beighton scores (area under the curve, 0.75).

TABLE 3
Baseline Patient-Reported Outcome Measures of Patients With and Without a High-Grade Pivot Shift[a]

	High-Grade Pivot,[b] Mean ± SE			
	No (n = 514)	Yes (n = 72)	Mean Difference (95% CI)	*P* Value
IKDC	54.0 ± 0.7	52.4 ± 2.0	1.5 (–2.6 to 5.6)	.47
ACL-QOL	29.5 ± 0.6	27.7 ± 1.7	1.8 (–1.8 to 5.4)	.33
P4	8 ± 14	11 ± 13	—	.04
KOOS	59.9 ± 0.7	58.6 ± 2.0	1.3 (–2.9 to 5.5)	.27
Pain	72.5 ± 0.7	71.5 ± 2.1	1.0 (3.5 to 5.4)	.67
Symptoms	67.6 ± 0.8	68.5 ± 2.2	–0.9 (–5.5 to 3.7)	.70
ADL	83.4 ± 0.7	79.3 ± 2.1	4.0 (–0.4 to 8.5)	.07
Sport	43.4 ± 1.0	41.7 ± 2.8	1.7 (–4.3 to 7.6)	.57
QOL	33.4 ± 0.8	31.9 ± 2.4	1.5 (–3.4 to 6.4)	.55

[a]Dash indicates Median ± IQR and Mann-Whitney U test were used to compare non-normally distributed data. ACL, anterior cruciate ligament; ACL-QOL, ACL Quality of Life questionnaire; ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, Quality of Life.

[b]The following patients were excluded (n = 32): 11 with baseline patient-reported outcome measures recorded within the 30 days of injury, 8 with missing baseline pivot-shift grade, and 13 with missing baseline patient-reported outcome scores.

DISCUSSION

The most important finding of this study was that specific patient and injury factors were independently associated with a high-grade pivot shift. Ligamentous laxity as assessed by the Beighton score was highlighted as a statistically and clinically significant predictor of a high-grade pivot shift, with diagnostic utility improved in the presence of knee hyperextension. Posterior third medial and lateral meniscal pathology, increased posterior tibial slope, injury chronicity, and male sex were also associated with a high-grade pivot shift, although the association was weak for chronicity and for posterior third lateral meniscal injury. Importantly, there was an interaction between posterior third medial meniscal injury and tibial slope in predicting a high-grade pivot. Preoperative assessment of pivot-shift grade in the awake patient is sometimes difficult. All 7 predictive variables are potentially identifiable preoperatively and may alert the surgeon to a high-grade pivot shift during examination under anesthesia. It is unclear if patients with a high-grade pivot shift should be treated differently; however, some have suggested that anterolateral augmentation should be investigated as a treatment strategy.[25] This data set contributes to the existing knowledge base in helping to understand the factors that are associated with a high-grade pivot shift, and it describes the relationship between a high-grade pivot shift and baseline PROMs.

There are conflicting data regarding the effect of ligamentous laxity on pivot-shift grade. Ligamentous laxity was the strongest predictor of a high-grade pivot shift (OR, 3.46; $P < .001$) in a study by Magnussen et al,[26] who reported on a cohort of 2318 patients from the Multicenter Orthopaedic Outcomes Network (MOON) ACL prospective cohort. In that study, the pivot shift was performed with the patient under anesthesia, and ligamentous laxity was classified according to the IKDC system as tight, normal, or lax. For their analysis, it was dichotomized as lax or not. The results of the current study support the finding of Magnussen et al[26] that ligamentous laxity is associated with a high-grade pivot shift. In our study, for each additional point in the Beighton score, there was 17% greater odds of a high-grade pivot shift. Knee hyperextension was shown to be an important component of the Beighton score, with improved model fit observed when knee hyperextension was present. Others, however, have found contradictory results regarding the effect of ligamentous laxity. Sundemo et al[45] analyzed the pivot shift of 93 patients with ACL injury, using an inertial sensor to measure joint acceleration and an image analysis system to measure lateral compartment translation. No correlation was found between either the degree of joint acceleration or the amount of lateral compartment translation and the Beighton score in the awake or anaesthetized patient. When subgroups with high (5-9 points) and low (0-4 points) Beighton scores were compared, there was no significant difference in the image analysis or accelerometer results between groups in terms of the involved knee, noninvolved knee, or side-to-side differences.

In the post hoc exploratory analysis, the presence of knee hyperextension (in either knee) was substituted for Beighton score. Patients with knee hyperextension were 2.3 times more likely to have a high-grade pivot shift than were those without hyperextension. These results correspond with those reported in a study by Saita et al,[39] who examined 54 ACL-deficient knees using the Kinematic Rapid Assessment Device. Using multivariable analysis, the range of passive knee extension was the only significant factor associated with anterolateral rotatory instability ($t = 2.21$; $P = .035$). The authors divided patients into pivot shift positive– and pivot shift–negative groups based on a 0.9-m/s^2 side-to-side difference in tibial acceleration as measured using the kinematic assessment device. Ipsilateral knee hyperextension, as measured using a goniometer with the patient under spinal anesthesia, significantly increased the odds of a positive pivot shift in a logistic regression model (OR, 3.08; $P = .047$).

Knee hyperextension has also been highlighted as a risk factor for failure of primary and revision ACL reconstruction. Larson et al[21] reported that passive absolute heel height >5 cm was independently predictive of failure in 226 consecutive patients undergoing primary ACL reconstruction by a single surgeon. Interestingly, knee hyperextension as measured by a goniometer was not predictive. In a prospective study, Cooper et al[7] demonstrated that passive knee hyperextension $\geq 5^\circ$ was an independent predictor of graft failure after revision ACL reconstruction (OR, 2.1; 95% CI, 1.02-4.42). Neither of these studies controlled for pivot-shift grade, which is a possible confounder.

Collectively, these studies highlight a 3-way relationship among knee hyperextension, higher rotatory laxity, and inferior surgical outcomes. An increase in knee hyperextension has been shown to result in an increase in anterior tibial translation.[46] As patholaxity associated with the pivot shift is essentially an anterolateral subluxation, an increase in anterior tibial translation will accentuate the phenomenon—hence, the reason why posteromedial meniscal lesions are also associated with increased pivot. Patients with passive knee hyperextension remain a challenging cohort for surgeons performing ACL reconstructions.

There was an interaction between tibial slope and posterior third medial meniscal pathology. Injury to the posterior third of the medial meniscus was associated with a high-grade pivot, regardless of whether the tibial slope was $<9^\circ$ or $>9^\circ$. However, if the posterior third of the medial meniscus was intact, only a tibial slope $>9^\circ$ was associated with a high-grade pivot shift. This suggests that the effect of tibial slope may be accentuated by the presence of posterior third meniscal injury, and it supports the need for meniscal preservation.

Importantly, bony tibial slope measurements do not account for articular cartilage and meniscal contributions to tibial slope, which is the actual surface on which the femur moves. In the current study, tibial slope $>9^\circ$ was associated with 2.35 times the odds of a high-grade pivot shift. This is in agreement with the results of Rahnemai-Azar et al[36] who observed a higher mean lateral tibial slope of $9.3^\circ \pm 3.4^\circ$ in patients with high-grade rotatory laxity as compared with a mean tibial slope of $6.1^\circ \pm 3.7^\circ$ in patients with low-grade rotatory laxity. In their study, for every degree of increase in lateral tibial plateau slope, there was a 27.5% risk increase of high-grade rotatory laxity. Medial meniscal injuries were seen in 35%, and lateral meniscal injuries were seen in 35%, although the interaction between meniscal injury and slope was not explored.

In our model, posterior third medial meniscal injury was associated with a high-grade pivot shift in this series, with an OR of 2.55 ($P = .03$). A similar finding was shown by the MOON group, albeit with a slightly lower OR of 1.53 ($P < .001$).[26] The possible reason for the increased OR in the current study is that we included posterior third injury only, which is believed to be a more important restraint to anterior tibial translation.[1,4] Furthermore, bucket-handle tears were not included in our analysis, and these may reduce the grade of the pivot shift by stopping the knee from gliding.

Injury or deficiency of the posterior third of the lateral meniscus was also associated with a high-grade pivot shift; yet, the OR was smaller than that for the medial meniscus (1.76), and this just reached statistical significance ($P = .048$). This finding was somewhat surprising because lateral meniscal injury has been more commonly associated with increased pivot-shift grade in both clinical[8,17,23,26,34] and biomechanical studies.[24] This may be explained by the fact that there was a small number of posterior lateral meniscus root tears and that the presence of a tear did not necessarily indicate a deficient lateral meniscus.

According to a 2019 systematic review, the medial meniscus was important for anteroposterior stability, and the lateral meniscus appeared to be a more important restraint of rotational and dynamic laxity.[13] This suggests that the lateral meniscus had a greater effect on the pivot shift; the medial meniscus, on the Lachman test. It is also possible that medial meniscal injury could be an effect (rather than a cause) of high-grade rotatory laxity. Higher rates of medial meniscal injury have been reported with increased time between injury and ACL reconstruction, likely attributed to medial meniscal injury occurring during recurrent episodes of instability.[29,41]

Male patients were 74% more likely to have a high-grade pivot shift in this study. Sex has been examined in many series, the largest of which was the MOON cohort as reported by Magnussen et al.[26] They found that female patients were approximately 50% more likely than their male counterparts to have a high-grade pivot shift ($P = .001$). Similarly, Pfeiffer et al[35] found that during a standardized pivot shift evaluated using iPad-based image analysis, anterior translation of the lateral compartment during the pivot-shift test was significantly higher in female patients (median, 1.6 mm; range, 0.3-4.9 mm) than in male patients (median, 1.1 mm; range, 0.1-7.1 mm; $P < .05$). In other series, sex did not influence pivot-shift grade.[8,23,34,42] It is difficult to account for these discrepancies among studies, and there is no clear clinical or biological explanation for this finding.

Previous investigations into predictors of a high-grade pivot shift typically have had smaller patient cohorts[8,23,34,35,42] and used a variety of methods to grade the pivot shift, including clinical examination via the IKDC system[26,42] and the modified IKDC system,[8] as well as quantitative assessments using custom iPad software[23,35] or an electromagnetic system.[34] It is possible that these factors contribute to some of the discrepancy among studies. We had hypothesized that female sex was more likely associated with ligamentous laxity, but there was no interaction between these variables in our data set. Similarly, there was no interaction between sex and chronicity. It is possible that male and female athletes play different sports that may have differing injury profiles or mechanisms for which we did not account. It is also possible that no such association exists between sex and the presence of a high-grade pivot shift and that this result is due to type 1 error; however, the OR was one of the stronger predictors and was strongly significant ($P = .005$).

Previous studies have shown that knees with chronic ACL deficiency have an increased chance of having a high-grade pivot shift.[26,34] The time frame when this becomes apparent has been reported as 6 months[26] and 12 months.[34] This may be a result of progressive damage or attenuation of secondary stabilizers. In the current study, there was an association between chronicity and high-grade pivot; however, the OR was lower at 1.7, and this just reached statistical significance ($P = .049$).

In treating a patient with a high-grade pivot shift, some of these risk factors are modifiable. While age, sex, and Beighton score cannot be addressed, tibial slope, chronicity, and meniscal injury are potentially changeable. Slope-reducing osteotomy is not without surgical morbidity, and the indications need to be refined, especially in the primary

ACL reconstruction setting. These data do support intervention before 6 months for patients who require ACL reconstruction surgery as well as meniscal preservation where possible. Further work is required to confirm that these alter the natural history in patients with a high-grade pivot shift.

Patients with a high-grade pivot shift had baseline PROMs similar to those without, except for a slightly higher P4 pain score. This was statistically significant but clinically insignificant. Patient factors have been shown to influence baseline PROMs in patients with ACL-deficient knees.[10,33] In a systematic review of randomized controlled trials, Ayeni et al[2] demonstrated that the postoperative pivot shift is correlated with functional outcomes. Eradicating of the pivot shift is widely regarded as the technical goal of ACL reconstruction surgery.[12] In this context, we hypothesized that patients with higher grades of rotatory laxity would have lower baseline PROMs, although this was not observed except for the P4 pain score. This difference in mean baseline P4 scores was only 3 and just reached statistical significance ($P = .04$). This is unlikely to be clinically significant, as it does not meet the minimal detectable change for the P4 scale, which is 9.[43] Furthermore, the KOOS Pain scores were similar between groups, adding doubt to the clinical significance of this finding.

The lack of association between baseline high-grade rotatory laxity and baseline PROMs was somewhat surprising and difficult to explain, especially as higher baseline laxity has been associated with inferior PROMs after ACL reconstruction.[27] The MOON study group reported that higher body mass index, female sex, lateral collateral ligament injury, and older age were the only factors associated with baseline KOOS Pain and Symptoms scores.[10] The pivot shift was not assessed in the MOON study, but Lachman testing was not found to be related. In the current study, there are multiple potential explanations for a lack of a relationship between pivot shift and baseline PROMs. It is possible that there truly was no association. It is also possible that the study was underpowered to detect a difference that existed. It is possible that as patients modified their activities after ACL injury, symptoms of instability were reduced. The PROMs used may not have been sensitive enough to detect a true difference. It is also possible that the measurement tool for assessing rotatory laxity (pivot shift in the anaesthetized patient) was not accurate enough to adequately define patient groups.

Others, however, have found that a quantitative pivot shift measuring preoperative laxity and residual laxity at time zero after ACL reconstruction is not correlated with PROMs at 24-month follow-up.[9] Finally, it is possible that laxity may not always be correlated with functional stability and that certain patients could compensate for an ACL-deficient knee and maintain a high functional profile and low pain profile. Regardless, further data sets are needed to better understand this.

Limitations

There are some limitations with this investigation. This was a post hoc analysis of a randomized controlled trial with specific inclusion and exclusion criteria. Therefore, the population was not necessarily reflective of the general ACL-injured population, and there were relatively few patients with a grade 1 pivot. This large group of active patients deemed high risk for reinjury is an important subgroup of patients in whom operative management is commonly recommended.

Operatively managed multiligament knee injuries were excluded; yet, this is a surgical threshold, and it is possible that lower-grade injuries to other ligamentous complexes or capsular injuries affected the pivot-shift grade. There is undoubtedly interrater variation when the pivot shift is assessed, but all assessors were experienced with this examination and with the IKDC grading system. Despite progress in quantification of the pivot shift using various devices, these have not yet reached the point where they are a standard of care and used routinely in the clinical environment. Clinical examination with IKDC grading reflects current clinical practice and the information available to most surgeons when planning treatment.

A number of potentially contributory factors were not assessed in this model. Notable examples include the presence of a pivot shift in the contralateral noninjured knee, anterolateral injury,[11] and distal femoral osseous morphology. Despite this and given the low prevalence of a high-grade pivot shift, adding these factors to the model would risk overfitting. Clearly, massive data sets are required to precisely define these factors and avoid model overfitting. Although we acknowledge these limitations, this is the second-largest series of which we are aware to use a multivariable model to evaluate factors associated with a high-grade pivot shift.

CONCLUSION

Ligamentous laxity, male sex, posterior third pathology of either the medial or lateral meniscus, tibial slope, and injury chronicity were associated with a high-grade preoperative pivot shift. Knee hyperextension was an important element of the Beighton score in predicting a high-grade pivot shift. The effect of posterior tibial slope may be accentuated by the presence of medial meniscal injury, potentially supporting the importance of meniscal preservation and repair during ACL surgery. Patients with a high-grade pivot had baseline PROMs similar to those without it, with the exception of a clinically insignificant increase in the P4 pain scale.

ACKNOWLEDGMENT

The authors acknowledge funding support from the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine.

AUTHORS

Lachlan M. Batty, MBBS (Fowler Kennedy Sport Medicine Clinic, Western University, London, Ontario, Canada;

Orthosport, Melbourne, Australia); Andrew Firth, MSc (Fowler Kennedy Sport Medicine Clinic, Western University, London, Ontario, Canada); Gilbert Moatshe, MD, PhD (Fowler Kennedy Sport Medicine Clinic, Western University, London, Ontario, Canada; University of Oslo, Oslo, Norway); Dianne M. Bryant, PhD (Western University, London, Ontario, Canada); Mark Heard, MD (Banff Sport Medicine, Banff, Alberta, Canada); Robert G. McCormack, MD (Fraser Health Authority, New Westminster, British Columbia, Canada); Alex Rezansoff, MD (Sport Medicine Centre, University of Calgary, Calgary, Alberta, Canada); Devin C. Peterson, MD (McMaster University, Hamilton, Ontario, Canada); Davide Bardana, MD (Queens University, Kingston, Ontario, Canada); Peter B. MacDonald, MD (Pan Am Clinic, Winnipeg, Manitoba, Canada); Peter C.M. Verdonk, MD, PhD (ORTHOCA, Antwerp, Belgium); Tim Spalding, MBBS (University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK); Alan M.J. Getgood, MD (Fowler Kennedy Sport Medicine Clinic, Western University, London, Ontario, Canada).

STABILITY Study Group: Kevin Willits, MD; Trevor Birmingham, PhD; Chris Hewison, MSc; Stacey Wanlin; Andrew Firth, MSc; Ryan Pinto, MSc; Ashley Martindale; Lindsey O'Neill, MSc; Morgan Jennings, MSc; Michal Daniluk, MSc (London Health Science Centre, Fowler Kennedy Sport Medicine Clinic, Western University, London, Ontario, Canada); Dory Boyer, MD; Mauri Zomar, CCRP; Karyn Moon; Raely Pritchett; Krystan Payne; Brenda Fan; Bindu Mohan (Fraser Health Authority, New Westminster, British Columbia, Canada); Gregory M. Buchko, MD; Laurie A. Hiemstra, MD, PhD; Sarah Kerslake; Jeremy Tynedal (Banff Sport Medicine, Banff, Alberta, Canada); Greg Stranges, MD; Sheila Mcrae, MSc, PhD; LeeAnne Gullett; Holly Brown; Alexandra Legary; Alison Longo; Mat Christian; Celeste Ferguson (Pan Am Clinic, Winnipeg, Manitoba, Canada); Nick Mohtadi, MD; Rhamona Barber; Denise Chan; Caitlin Campbell; Alexandra Garven; Karen Pulsifer; Michelle Mayer (Sport Medicine Centre, University of Calgary, Calgary, Alberta, Canada); Nicole Simunovic; Andrew Duong; David Robinson; David Levy; Matt Skelly; Ajaykumar Shanmugaraj (McMaster University, Hamilton, Ontario, Canada); Fiona Howells; Murray Tough (Queens University, Kingston, Ontario, Canada); Pete Thompson; Andrew Metcalfe; Laura Asplin; Alisen Dube; Louise Clarkson; Jaclyn Brown; Alison Bolsover; Carolyn Bradshaw; Larissa Belgrove; Francis Millan; Sylvia Turner; Sarah Verdugo; Janet Lowe; Debra Dunne; Kerri McGowan; Charlie-Marie Suddens (University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK); Geert Declercq, MD; Kristien Vuylsteke; Mieke Van Haver (ORTHOCA, Antwerp, Belgium).

REFERENCES

1. Arno S, Hadley S, Campbell KA, et al. The effect of arthroscopic partial medial meniscectomy on tibiofemoral stability. *Am J Sports Med*. 2013;41(1):73-79.
2. Ayeni OR, Chahal M, Tran MN, Sprague S. Pivot shift as an outcome measure for ACL reconstruction: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(4):767-777.
3. Babyak MA. What you see may not be what you get: a brief, nontechnical introduction to overfitting in regression-type models. *Psychosom Med*. 2004;66(3):411-421.
4. Bargar WL, Moreland JR, Markolf KL, Shoemaker SC, Amstutz HC, Grant TT. In vivo stability testing of post-meniscectomy knees. *Clin Orthop Relat Res*. 1980;150:247-252.
5. Batty LM, Murgier J, Feller JA, O'Sullivan R, Webster KE, Devitt BM. Radiological identification of injury to the Kaplan fibers of the iliotibial band in association with anterior cruciate ligament injury. *Am J Sports Med*. 2020;48(9):2213-2220.
6. Beighton P, Solomon L, Soskolne C. Articular mobility in an African population. *Ann Rheum Dis*. 1973;32(5):413.
7. Cooper DE, Dunn WR, Wright RW, Haas A, Huston LJ. Knee hyperextension as a predictor of failure in revision ACL reconstruction: a prospective cohort study. *Orthop J Sports Med*. 2016;4(7)(suppl 4):2325967116S00187.
8. Cui W, Nakagawa Y, Katagiri H, et al. Knee laxity, lateral meniscus tear and distal femur morphology influence pivot shift test grade in ACL injury patients. *Knee Surg Sports Traumatol Arthrosc*. Published online April 17, 2020. doi:10.1007/s00167-020-05994-7
9. Diermeier T, Meredith SJ, Irrgang JJ, et al. Patient-reported and quantitative outcomes of anatomic anterior cruciate ligament reconstruction with hamstring tendon autografts. *Orthop J Sports Med*. 2020;8(7):2325967120926159.
10. Dunn WR, Spindler KP, Amendola A, et al. Which preoperative factors, including bone bruise, are associated with knee pain/symptoms at index anterior cruciate ligament reconstruction (ACLR)? A Multicenter Orthopaedic Outcomes Network (MOON) ACLR cohort study. *Am J Sports Med*. 2010;38(9):1778-1787.
11. Ferretti A, Monaco E, Gaj E, et al. 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. *Am J Sports Med*. 2020;48(10):2408-2417.
12. Getgood AM, Bryant DM, Litchfield R, et al. Lateral extra-articular tenodesis reduces failure of hamstring tendon autograft anterior cruciate ligament reconstruction: 2-year outcomes from the STABILITY Study randomized clinical trial. *Am J Sports Med*. 2020;48(2):285-297.
13. Grassi A, Dal Fabbro G, Di Paolo S, et al. Medial and lateral meniscus have a different role in kinematics of the ACL-deficient knee: a systematic review. *J ISAKOS*. 2019;4(5):233-241.
14. Hair JF, Anderson RE, Tatham RL, Black W. *Multivariate Data Analysis*. Macmillan; 1995.
15. Hefti E, Müller W, Jakob R, Stäubli H-U. Evaluation of knee ligament injuries with the IKDC form. *Knee Surg Sports Traumatol Arthrosc*. 1993;1(3-4):226-234.
16. Higgins LD, Taylor MK, Park D, et al. Reliability and validity of the International Knee Documentation Committee (IKDC) subjective knee form. *Joint Bone Spine*. 2007;74(6):594-599.
17. Hoshino Y, Miyaji N, Nishida K, et al. The concomitant lateral meniscus injury increased the pivot shift in the anterior cruciate ligament–injured knee. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(2):646-651.
18. Irrgang JJ, Anderson AF, Boland AL, et al. Development and validation of the International Knee Documentation Committee subjective knee form. *Am J Sports Med*. 2001;29(5):600-613.
19. Jonsson H, Riklund-Åhlström K, Lind J. Positive pivot shift after ACL reconstruction predicts later osteoarthrosis: 63 patients followed 5-9 years after surgery. *Acta Orthop Scand*. 2004;75(5):594-599.
20. Kocher MS, Micheli LJ, Zurakowski D, Luke A. Partial tears of the anterior cruciate ligament in children and adolescents. *Am J Sports Med*. 2002;30(5):697-703.
21. Larson CM, Bedi A, Dietrich ME, et al. Generalized hypermobility, knee hyperextension, and outcomes after anterior cruciate ligament reconstruction: prospective, case-control study with mean 6 years follow-up. *Arthroscopy*. 2017;33(10):1852-1858.

22. Lian J, Diermeier T, Meghpara M, et al. Rotatory knee laxity exists on a continuum in anterior cruciate ligament injury. *J Bone Joint Surg Am*. 2020;102(3):213-220.
23. Lian J, Novaretti JV, Sheean AJ, et al. Static lateral tibial plateau subluxation predicts high-grade rotatory knee laxity in anterior cruciate ligament–deficient knees. *Am J Sports Med*. 2019;47(2):277-284.
24. Lording T, Corbo G, Bryant D, Burkhart TA, Getgood A. Rotational laxity control by the anterolateral ligament and the lateral meniscus is dependent on knee flexion angle: a cadaveric biomechanical study. *Clin Orthop Relat Res*. 2017;475(10):2401-2408.
25. Magnussen RA. Editorial commentary: so your knee has a big pivot shift before anterior cruciate ligament surgery—why does that matter? *Arthroscopy*. 2020;36(5):1407-1408.
26. Magnussen RA, Reinke EK, Huston LJ, et al. Factors associated with high-grade Lachman, pivot shift, and anterior drawer at the time of anterior cruciate ligament reconstruction. *Arthroscopy*. 2016;32(6):1080-1085.
27. Magnussen RA, Reinke EK, Huston LJ, et al. Effect of high-grade preoperative knee laxity on 6-year anterior cruciate ligament reconstruction outcomes. *Am J Sports Med*. 2018;46(12):2865-2872.
28. MARS Group; Wright RW, Huston LJ, Haas AK, et al. Predictors of patient-reported outcomes at 2 years after revision anterior cruciate ligament reconstruction. *Am J Sports Med*. 2019;47(10):2394-2401.
29. Millett PJ, Willis AA, Warren RF. Associated injuries in pediatric and adolescent anterior cruciate ligament tears: does a delay in treatment increase the risk of meniscal tear? *Arthroscopy*. 2002;18(9):955-959.
30. Mohtadi N. Development and validation of the quality of life outcome measure (questionnaire) for chronic anterior cruciate ligament deficiency. *Am J Sports Med*. 1998;26(3):350-359.
31. Muller B, Yabroudi MA, Lynch A, et al. Defining thresholds for the Patient Acceptable Symptom State for the IKDC subjective knee form and KOOS for patients who underwent ACL reconstruction. *Am J Sports Med*. 2016;44(11):2820-2826.
32. Musahl V, Rahnemai-Azar AA, Costello J, et al. The influence of meniscal and anterolateral capsular injury on knee laxity in patients with anterior cruciate ligament injuries. *Am J Sports Med*. 2016;44(12):3126-3131.
33. Nguyen JT, Wasserstein D, Reinke EK, et al. Does the chronicity of anterior cruciate ligament ruptures influence patient-reported outcomes before surgery? *Am J Sports Med*. 2017;45(3):541-549.
34. Nishida K, Matsushita T, Hoshino Y, et al. The influences of chronicity and meniscal injuries on pivot shift in anterior cruciate ligament–deficient knees: quantitative evaluation using an electromagnetic measurement system. *Arthroscopy*. 2020;36(5):1398-1406.
35. Pfeiffer TR, Kanakamedala AC, Herbst E, et al. Female sex is associated with greater rotatory knee laxity in collegiate athletes. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(5):1319-1325.
36. Rahnemai-Azar AA, Abebe ES, Johnson P, et al. Increased lateral tibial slope predicts high-grade rotatory knee laxity pre-operatively in ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(4):1170-1176.
37. Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): from joint injury to osteoarthritis. *Health Qual Life Outcomes*. 2003;1:64.
38. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee injury and Osteoarthritis Outcome Score (KOOS)—development of a self-administered outcome measure. *J Orthop Sports Phys Ther*. 1998;28(2):88-96.
39. Saita Y, Schoenhuber H, Thiébat G, et al. Knee hyperextension and a small lateral condyle are associated with greater quantified anterolateral rotatory instability in the patients with a complete anterior cruciate ligament (ACL) rupture. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(3):868-874.
40. Shybut TB, Vega CE, Haddad J, et al. Effect of lateral meniscal root tear on the stability of the anterior cruciate ligament–deficient knee. *Am J Sports Med*. 2015;43(4):905-911.
41. Sommerfeldt M, Goodine T, Raheem A, Whittaker J, Otto D. Relationship between time to ACL reconstruction and presence of adverse changes in the knee at the time of reconstruction. *Orthop J Sports Med*. 2018;6(12):2325967118813917.
42. Song G-Y, Zhang H, Wang Q-Q, Zhang J, Li Y, Feng H. Risk factors associated with grade 3 pivot shift after acute anterior cruciate ligament injuries. *Am J Sports Med*. 2016;44(2):362-369.
43. Spadoni GF, Stratford PW, Solomon PE, Wishart LR. The evaluation of change in pain intensity: a comparison of the P4 and single-item numeric pain rating scales. *J Orthop Sports Phys Ther*. 2004;34(4):187-193.
44. Stratford PW, Dogra M, Woodhouse L, Kennedy DM, Spadoni GF. Validating self-report measures of pain and function in patients undergoing hip or knee arthroplasty. *Physiother Can*. 2009;61(4):189-194.
45. Sundemo D, Blom A, Hoshino Y, et al. Correlation between quantitative pivot shift and generalized joint laxity: a prospective multicenter study of ACL ruptures. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(8):2362-2370.
46. Sundemo D, Mikkelsen C, Cristiani R, et al. Contralateral knee hyperextension is associated with increased anterior tibial translation and fewer meniscal injuries in the anterior cruciate ligament–injured knee. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(10):3020-3028.
47. Ueki H, Nakagawa Y, Ohara T, et al. Risk factors for residual pivot shift after anterior cruciate ligament reconstruction: data from the MAKS group. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(12):3724-3730.
48. Webb JM, Salmon LJ, Leclerc E, Pinczewski LA, Roe JP. Posterior tibial slope and further anterior cruciate ligament injuries in the anterior cruciate ligament–reconstructed patient. *Am J Sports Med*. 2013;41(12):2800-2804.
49. Yamamoto Y, Tsuda E, Maeda S, et al. Greater laxity in the anterior cruciate ligament–injured knee carries a higher risk of postreconstruction pivot shift: intraoperative measurements with a navigation system. *Am J Sports Med*. 2018;46(12):2859-2864.