The Reproducibility and Repeatability of Varus Stress Radiographs in the Assessment of Isolated Fibular Collateral Ligament and Grade-III Posterolateral Knee Injuries

An in Vitro Biomechanical Study

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Background: Objective measures to quantitate the amount of lateral compartment opening for patients with lateral and posterolateral knee injuries have not been well documented. The purpose of the present study was to measure lateral compartment opening secondary to applied varus stresses following posterolateral corner structure sectioning and to develop radiographic guidelines to quantify the amount of lateral compartment gapping seen with these injuries.

Methods: Ten nonpaired fresh-frozen cadaver lower extremities were used. Two varus loads, a 12-Nm moment and a clinician-applied varus stress, were applied to the intact knees and after sequential sectioning of the fibular collateral ligament, popliteus tendon, popliteofibular ligament, and anterior and posterior cruciate ligaments to simulate degrees of posterolateral knee and associated combined cruciate ligament injuries. The shortest distance between the most distal subchondral bone surface of the lateral femoral condyle and the corresponding lateral tibial plateau was measured to quantify lateral compartment opening and was analyzed on digital radiographs. Three observers were used to determine interobserver reproducibility and intraobserver repeatability.

Results: In the intact knee, the mean lateral compartment gapping due to a 12-Nm moment and a clinician-applied varus stress was 8.9 and 9.7 mm, respectively. Lateral gapping significantly increased by 2.1 and 2.7 mm in association with sectioning of the fibular collateral ligament and by 3.4 and 4.0 mm in knees with a simulated posterolateral corner injury for each respective load-application technique ($p < 0.0001$ for all comparisons). Intraobserver repeatability was high, with all observers independently obtaining an intraclass correlation coefficient of 0.99, whereas the analysis of interobserver reproducibility demonstrated an intraclass correlation coefficient of 0.97.

Conclusions: Measurements with use of current clinical digital imaging systems can be used to quantify the amount of lateral compartment knee opening. Clinicians should suspect an isolated fibular collateral ligament injury if opening on clinician-applied varus stress radiographs increases by approximately 2.7 mm and a grade-III posterolateral corner injury if values increase by approximately 4.0 mm.

Clinical Relevance: Varus stress radiographs appear to provide an objective and reproducible measure of lateral compartment gapping that should prove useful for the diagnosis, management, and postoperative follow-up of patients with fibular collateral ligament and posterolateral knee injuries.

Injuries to the fibular collateral ligament and other posterolateral corner structures can be difficult to diagnose on physical examination of the knee, especially in the setting of concurrent cruciate ligament injuries. Previous authors have recognized the difficulty of relying solely on physical examination and have sought tools to quantify instability in order to facilitate accurate diagnosis, to facilitate preoperative and postoperative examinations, and to establish values to be used

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for outcome measures of posterolateral knee surgical techniques[1-4]. Complicating matters is the knowledge that the timing of treatment has an effect on long-term outcome, with several studies demonstrating that acute repairs fare better than delayed reconstructions[5-8]. Finally, reconstructed cruciate ligaments often fail in the setting of unrecognized or undertreated varus instability due to fibular collateral ligament or posterolateral knee injuries because other considerable stress is being placed on the grafts[9-12]. This makes it important to be able to accurately diagnose concurrent posterolateral knee injuries. Therefore, in addition to a careful and thorough history and physical examination, ancillary tests including plain radiographs and magnetic resonance imaging are commonly utilized to help diagnose these injuries[13].

The amount of abnormal lateral compartment gapping that occurs with posterolateral knee injuries has not been defined. There have been several biomechanical sectioning studies[14-16] and clinical studies on normal knees[2,4,17] that have measured varus rotation or lateral compartment gapping. However, those studies varied substantially with regard to knee position, moments applied, and the units of measurement (i.e., degrees[4,14-17] as opposed to millimeters[2] of lateral compartment opening). While varus stress radiographs have been recommended as a diagnostic tool for the evaluation of patients with posterolateral knee injuries[2,8], we are not aware of any studies that have quantified the amount of lateral compartment opening that occurs with these injuries. It is important to accurately determine the true amount of increased lateral compartment opening to be able to properly interpret findings from both the clinical evaluation and the varus stress radiographs.

Objective measurement guidelines to assist the clinician in the identification of posterolateral knee injuries, to compare studies, and to assess surgical outcomes of surgical techniques have not been described, to our knowledge. The purpose of the present study was to measure lateral compartment opening secondary to applied varus moments following posterolateral corner structure sectioning and to develop radiographic guidelines to quantify the amount of lateral compartment gapping seen with these injuries. In addition, we wished to analyze the repeatability of measurements of the amount of lateral compartment gapping that occurs in association with posterolateral knee injuries and also to assess if such gapping could be reproducibly quantified.

Materials and Methods

Specimen Preparation

Ten nonpaired fresh-frozen whole lower extremities (seven from male donors and three from female donors), with no evidence of surgical scars and no instability on clinical examination, were used in the present study. In addition, knees with evidence of osteoarthritis on fluoroscopic images or on examination of the knees during arthrotomy were excluded. We chose to use nonpaired knees because while it has been reported that there is little side-to-side variability between knees in the same patient[2,4], it has been reported that there is increased variability between different patients in terms of lateral compartment gapping[2,17]. The average age of the donors at the time of death had been 71.6 years (range, forty-three to seventy-nine years). The lower extremities were sectioned at the middle part of the thigh and were left intact distally. The lower extremities were kept frozen at −20°C until the night before testing and then were allowed to thaw at room temperature. Before testing, the skin and subcutaneous fat about the lateral aspect of the knee were removed to allow identification of the structures to be sectioned, leaving the investing fascia intact. The soft tissues were removed approximately 15 cm proximal to the knee to expose the femur. Two 4.0-mm-diameter tunnels, separated by 5 cm, were then drilled through the exposed femur from lateral to medial to allow fixation of the specimens to the testing jig. A fascial-splitting posterolateral approach[18] was used to gain access to the posterolateral structures of the knee, and the fibular collateral ligament, popliteofibular ligament, and popliteus tendon were identified and tagged with sutures. These three structures have been noted to be the primary static stabilizers of the posterolateral part of the knee. A mini-arthrotomy through a medial parapatellar approach was used to allow access to the anterior cruciate ligament and posterior cruciate ligament. The access incisions were closed with running sutures prior to biomechanical testing.

Biomechanical Testing

The femur was firmly secured with two 4.5-mm bicortical screws to a 20° fixed-angle radiolucent jig, with the joint line at the apex of the jig. To make our testing as clinically relevant to current testing guidelines as possible, we chose the angle of testing to be 20° according to the International Knee Documentation Committee (IKDC) reporting guidelines for lateral compartment joint opening[19,20]. The distal end of the leg was allowed to glide freely along the jig in either a medial or lateral direction. A radiopaque grid measuring 1 cm × 1 cm was placed directly under the proximal part of the tibia, at the joint line, to serve as a magnification correction guide. The jig with the secured specimen was then placed between two metallic tables and was attached firmly with clamps, leaving adequate room for a fluoroscopy C-arm (MiniView 6800 mobile imaging system; GE Healthcare, Milwaukee, Wisconsin), which was angled 20° caudad and perpendicular to the joint line (Fig. 1). Each specimen was then tested in the intact state and after sequential cutting of the fibular collateral ligament, the popliteus tendon, the popliteofibular ligament (with sectioning of all three of these structures being equivalent to a grade-III posterolateral knee injury[21]), the anterior cruciate ligament, and the posterior cruciate ligament, resulting in a total of six testing conditions. Two different loads were applied for each testing condition. The first load was a standardized 12-Nm varus moment that was applied manually through an S-type Load Cell (Interface, Scottsdale, Arizona) perpendicular to the tibia and 25 cm distal to the joint line. This load was chosen on the basis of previously reported applied varus stress loads[22]. The second load was a varus stress applied by a clinician (C.H.); one hand was placed at the medial femoral condyle, and the other hand was placed just proximal to the lateral

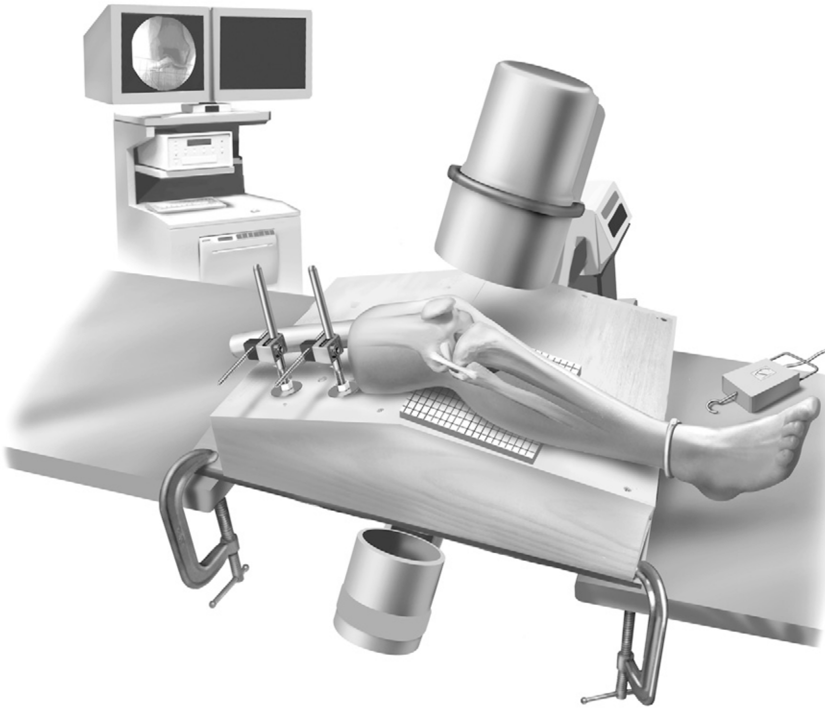

Fig. 1

Illustration depicting a lateral view of the varus stress testing setup, with the right knee flexed to 20° on the radiolucent jig, the fluoroscopy machine with imaging monitors, and the force meter device on the table.

malleolus to apply the varus moment. The same technique that is applied in our clinic several times daily for varus stress radiographs was used in all of the knees. Each testing condition was repeated three times, with one fluoroscopic image being made each time, resulting in a total of thirty-six radiographic images per knee.

Data Analysis

Images were stored in and accessed through the archives of the institution's picture archiving and communication system (PACS). With use of the measurement tool on the PACS, the closest perpendicular distance between the central aspect of the lateral femoral condyle and the corresponding lateral tibial plateau was determined (Fig. 2). For the purpose of the present study, "gapping" was defined as the shortest distance between the subchondral bone surface of the most distal aspect of the lateral femoral condyle and the corresponding lateral tibial plateau and did not take into account the thickness of the articular cartilage surfaces. The amount of displacement was measured in pixels with use of the PACS measurement tool. The length of a 5-cm section of the 1 cm × 1 cm grid was measured on each radiograph and was utilized to convert the lateral compartment gapping measurements into millimeters and to allow for correction of the magnification differences between radiographs.

We also graded the severity of the simulated injury with use of the 2000 IKDC knee examination form on the basis of the measured amounts of lateral compartment gapping in the present study. The IKDC first established an objective evaluation form for knee injuries in 1993[23] and later revised and expanded it with a subjective part[19]. For the purpose of the present study, we reported the grade of simulated injury as determined by the testing conditions specified and subsequently used the 2000 IKDC objective knee examination grading form for the amount of lateral compartment gapping measured with sequential structure sectioning. The scores for varus stress testing were determined according to the measured amount of lateral joint line opening and were classified as grade A (normal; 0 to 2 mm), grade B (nearly normal; 3 to 5 mm), grade C (abnormal; 6 to 10 mm), or grade D (severely abnormal; >10 mm).

Intraobserver Repeatability and Interobserver Reproducibility

Intraobserver repeatability was determined by having each of the three examiners measure the amount of lateral compartment gapping on the set of 360 radiographs twice, with the trials being performed two weeks apart. The radiographs were directly read off of the PACS file and were not reordered between observer readings. Interobserver reproducibility was determined by having three different examiners with different levels of training, including a medical student (A.J.B.; Observer 1), a chief orthopaedic resident (C.H.; Observer 2), and an orthopaedic sports medicine faculty member (R.F.L.; Observer 3), independently measure the varus stress radiographs for each knee.

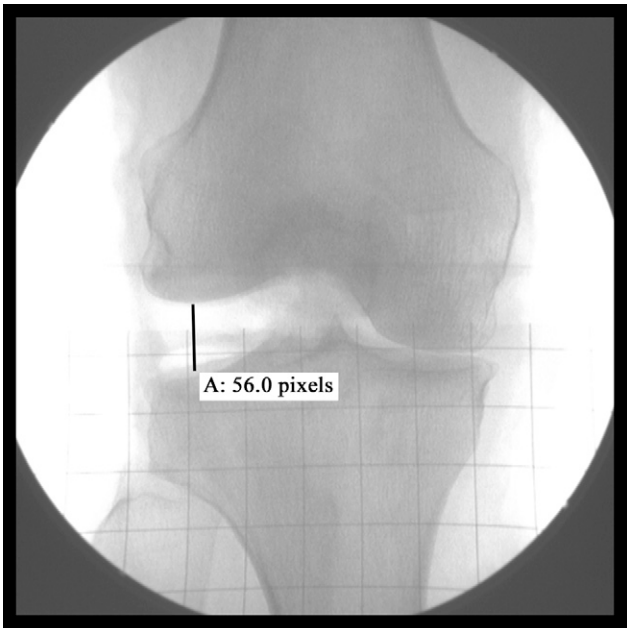

Fig. 2

Fluoroscopic image made after lateral structure sectioning with the application of the varus moment and an example of the measurement in pixels of lateral compartment gapping (note magnification grid) on the varus stress radiograph.

Statistical Analysis

Load, knee state, observer, and trial means were examined for differences with use of analysis of variance in repeated-measures mixed models with use of SAS software (SAS 9.1.3 for Windows; SAS Institute, Cary, North Carolina). In a model involving the use of the knee as the subject and the four factors listed previously as repeating measures, we examined second and third-order interactions *not* involving the subject (knee). With only the load-by-state interaction being significant ($p < 0.0001$), and with this interaction being a research focus, we then ran separate two-way repeated-measures analyses of variance for the two loads (state-by-knee model) and for the six sequential knee states (load-by-knee model). We compared least-squares means post hoc with use of the Bonferroni multiple-comparisons procedure. This is a conservative procedure that is biased toward reducing false differences. For the comparisons of loads (two means), states (six means), observers (three means), and trials (two means), the level of significance was set at $p < 0.025$, $p < 0.0083$, $p < 0.0167$, and $p < 0.025$, respectively.

Intraobserver and interobserver reproducibility were evaluated by comparing the means of lateral compartment gapping and by calculating intraclass correlation coefficients. Single-measure intraclass correlation coefficients for intraobserver and interobserver measurements were determined in a two-way random-effects model with an absolute agreement criterion with use of SPSS version 15 software (SPSS, Chicago, Illinois).

Ninety-five percent confidence intervals for the means were tabulated as the mean plus or minus two standard deviations. Confidence intervals for the intraclass correlation coefficients were taken verbatim from the SPSS output.

Results

Load and Knee States

In each knee state, the clinician-applied varus stress resulted in a significantly increased lateral compartment opening distance as compared with the 12-Nm moment ($p < 0.025$) (Table I). Overall, the mean gapping distances between the two different loading techniques were significantly different ($p < 0.0001$).

All of the comparisons of mean gapping distances demonstrated significant differences with increasing sequential

TABLE I Lateral Compartment Gapping Distances on Varus Stress Radiographs for Intact and Cut States in Response to Applied Loads

	Lateral Gapping* *(mm)*		
Knee State	12-Nm Moment	Clinician-Applied Varus Stress	P Value
Intact	8.87 (6.37 to 11.37)	9.73 (7.26 to 12.20)	<0.0001
Fibular collateral ligament	10.99 (7.81 to 14.38)	12.44 (9.04 to 15.84)	<0.0001
Popliteus tendon	11.81 (8.69 to 14.93)	13.27 (9.86 to 16.68)	<0.0001
Popliteofibular ligament	12.22 (9.27 to 15.18)	13.68 (10.44 to 16.93)	<0.0001
Anterior cruciate ligament	14.13 (7.79 to 20.47)	16.28 (9.08 to 23.49)	<0.0001
Posterior cruciate ligament	15.19 (7.74 to 22.65)	17.50 (8.89 to 26.11)	<0.0001
Overall	12.20 (5.90 to 28.50)	13.82 (6.44 to 21.19)	<0.0001

*The values are given as the mean, with the 95% confidence interval (calculated as the mean plus or minus two standard deviations) in parentheses. For each state, the p value was derived from six separate two-way repeated-measures analyses of variance (model, load by knee). The overall p value was derived from a repeated-measures model with all factors included (see text). In each state, and overall, the clinician-applied varus stress resulted in an increase in gapping in comparison with that observed in association with the 12-Nm moment. The increases were all significant ($p < 0.025$) according to the Bonferroni multiple-comparisons procedure.

TABLE II Comparisons Between Mean Lateral Compartment Gapping Distances on Varus Stress Radiographs for Intact and Cut States in Response to Applied Loads*

	Fibular Collateral Ligament	Popliteus Tendon	Popliteofibular Ligament	Anterior Cruciate Ligament	Posterior Cruciate Ligament
12-Nm moment					
Intact	2.12, p < 0.0001	2.94, p < 0.0001	3.35, p < 0.0001	5.26, p < 0.0001	6.32, p < 0.0001
Fibular collateral ligament	—	0.82, p < 0.0001	1.23, p < 0.0001	3.14, p < 0.0001	4.20, p < 0.0001
Popliteus tendon	—	—	0.41, p = 0.09 NS	2.32, p < 0.0001	3.38, p < 0.0001
Popliteofibular ligament	—	—	—	1.91, p < 0.0001	2.97, p < 0.0001
Anterior cruciate ligament	—	—	—	—	1.06, p < 0.0001
Clinician-applied varus stress					
Intact	2.71, p < 0.0001	3.54, p < 0.0001	3.95, p < 0.0001	6.55, p < 0.0001	7.77, p < 0.0001
Fibular collateral ligament	—	0.83, p < 0.0001	1.24, p < 0.0001	3.84, p < 0.0001	5.06, p < 0.0001
Popliteus tendon	—	—	0.41, p = 0.22 NS	3.01, p < 0.0001	4.23, p < 0.0001
Popliteofibular ligament	—	—	—	2.60, p < 0.0001	3.82, p < 0.0001
Anterior cruciate ligament	—	—	—	—	1.22, p < 0.0001

*The values are expressed as differences between mean increases in lateral compartment gapping distances, in millimeters, by load. P values were Bonferroni-adjusted from a two-way repeated-measures analysis of variance (model, state by knee) at each load. At both loads, all differences were significant (p < 0.0083) according to the Bonferroni multiple-comparisons procedure except for the comparison between the popliteus tendon and popliteofibular ligament-sectioning states. NS = not significant.

sectioning of structures at both loads (p < 0.0001), except for the comparisons between the popliteus tendon and popliteofibular ligament-sectioning states, which did not demonstrate significant differences for either of the two applied loads (Table II).

Intact State

The 12-Nm moment produced a mean lateral gapping of 8.9 mm. The clinician-applied varus stress produced a mean lateral gapping of 9.7 mm (Table I).

Fibular Collateral Ligament-Incised State

There was a significant change from the intact state for the fibular collateral ligament-sectioned state for both the standardized 12-Nm moment and the clinician-applied varus stress (Table I). In comparison with the intact state, lateral gapping increased by 2.1 mm in association with the standardized 12-Nm moment (p < 0.0001) and by 2.7 mm in association with the clinician-applied varus stress (p < 0.0001) (Table II). For this simulated injury, the scoring grade according to the 2000 IKDC knee examination form would be grade A (normal) for the 12-Nm applied moment and grade B (nearly normal) for the clinician-applied varus stress.

Fibular Collateral Ligament and Popliteus Tendon-Incised State

With the addition of popliteus tendon sectioning, significant increases in lateral compartment gapping were again reached for the 12-Nm moment and the clinician-applied varus stress (Table I). Compared with the fibular collateral ligament-incised state, lateral compartment gapping increased by 0.8 mm in association with the 12-Nm moment (p < 0.0001) and by 0.8 mm in association with the clinician-applied varus stress (p < 0.0001) (Table II). Compared with the intact state, lateral compartment gapping increased by 2.9 mm in association with the 12-Nm moment (p < 0.0001) and by 3.5 mm in association with the clinician-applied varus stress (p < 0.0001). For this simulated injury, the IKDC knee examination score would be A (normal) for the 12-Nm moment and B (nearly normal) for the clinician-applied varus stress.

Posterolateral Corner (Fibular Collateral Ligament, Popliteus Tendon, and Popliteofibular Ligament)-Incised State

There were no significant differences associated with additional sectioning of the popliteofibular ligament for the 12-Nm moment or the clinician-applied varus stress as compared with the fibular collateral ligament and popliteus tendon-sectioned state, with both loads being associated with a 0.4-mm increase in lateral compartment opening (Table I). Compared with the intact state, lateral gapping was increased by 3.4 mm in association with the 12-Nm stress (p < 0.0001) and by 4.0 mm in association with the clinician-applied varus stress (p < 0.0001) (Table II). For this simulated posterolateral corner injury, the IKDC knee examination score for both loads would be B (nearly normal).

Posterolateral Corner and Anterior Cruciate Ligament-Incised State

Additional sectioning of the anterior cruciate ligament, simulating a combined anterior cruciate ligament and posterolateral corner injury, resulted in significant increases in gapping in association with the 12-Nm stress; specifically, gapping increased by 1.9 mm as compared with the posterolateral knee-sectioned state (p < 0.0001) and by 5.3 mm as compared with the intact state ($p < 0.0001$) (Tables I and II). Significant increases in gapping also were observed in association with the clinician-applied varus stress; specifically, gapping increased by 2.6 mm as compared with the posterolateral knee-sectioned state ($p < 0.0001$) and by 6.6 mm in comparison with the intact state ($p < 0.0001$). IKDC scores for this simulated injury would be B (nearly normal) for the 12-Nm moment and C (abnormal) for the clinician-applied varus stress.

Posterolateral Corner, Anterior Cruciate Ligament, and Posterior Cruciate Ligament-Incised State

Additional sectioning of the posterior cruciate ligament resulted in significant increases in gapping as compared with the posterolateral knee and anterior cruciate ligament-incised state; specifically, gapping increased by 1.1 mm in association with the 12-Nm moment ($p < 0.0001$) and by 1.2 mm in association with the clinician-applied varus stress ($p < 0.0001$) (Tables I and II). Compared with the intact state, gapping after additional sectioning of the posterior cruciate ligament was 6.3 mm ($p < 0.0001$) and 7.8 mm ($p < 0.0001$) in association with the 12-Nm moment and the clinician-applied varus stress, respectively. Both loads tested would represent an IKDC knee examination grade of C (abnormal).

Intraobserver and Interobserver Analysis

The intraobserver intraclass correlation coefficients for each of the individual observers were all 0.99 (see Appendix). The interobserver intraclass correlation coefficients for Trial 1, Trial 2, and the combined trials data sets were all 0.97 (see Appendix).

Discussion

We found that varus stress radiographs may be a useful clinical tool to detect both isolated fibular collateral ligament tears and grade-III posterolateral corner knee injuries[21]. We believe that the standard values of lateral compartment gapping observed in the present study may allow clinicians to use varus stress radiographs objectively to aid in the diagnosis of these complicated injury patterns. With use of a clinician-applied varus stress, radiographic measurement revealed a mean increase in lateral compartment gapping of 2.7 mm for an isolated fibular collateral ligament tear and 4.0 mm for a grade-III posterolateral knee injury when compared with the intact knee. Additional injury patterns that were studied suggested that one should suspect or recognize the potential presence of a combined posterolateral knee and anterior cruciate ligament injury on the basis of an increase in lateral gapping under a clinician-applied varus stress of approximately 6.6 mm with use of the intact knee as a control. Similarly, a combined anterior cruciate ligament, posterior cruciate ligament, and posterolateral knee injury should be considered if the increase in lateral gapping is approximately 7.8 mm.

Although there have been studies in which the investigators considered using radiographs as an objective tool to quantify posterolateral knee injuries, we are aware of only one study in which the author suggested that any change in lateral gapping that exceeds 2 mm when compared with the contralateral extremity is pathologic. Jacobsen[2] studied varus opening in normal subjects at 20° of knee flexion with a 9-kg applied load. The mean lateral compartment opening in normal knees was documented to be 9.2 mm, with a side-to-side difference of <2 mm. His conclusion was that an increase in gapping of >2 mm was diagnostic of pathologic injury to the collateral ligaments of the knee.

We found that if the IKDC system was applied to the objective results of the present study, substantial isolated and combined posterolateral knee injuries would be undergraded in terms of the severity of the injury. For example, we found that with a 12-Nm applied moment, an isolated injury of the fibular collateral ligament would still be considered normal, or grade A. Another example is a combined bicruciate and posterolateral corner injury. On the basis of our values, this injury pattern would result in a mean increase in lateral compartment gapping of 7.8 mm in association with the clinician-applied varus stress, which would be grade C, or abnormal, on the IKDC objective grading score. At no point in the present study did we observe a value with structure sectioning that would be considered a grade D, or a severely abnormal score, on the IKDC objective scoring form, a finding that we believe warrants a review of the quantitative portion of this commonly used rating system.

In addition, comparing our findings with values commonly referenced in the American Medical Association's *Standard Nomenclature of Athletic Injuries*[21] reveals similar reporting discrepancies. On close inspection, that book does not specifically address the gradation of knee injury severity, but it contains a widely referenced grading scale in which grade I represents mild opening (0 to 5 mm), grade II represents moderate opening (5 to 10 mm), and grade III represents complete opening (>10 mm)[24-26]. In spite of extensive literature searches, we have not been able to establish when these values were introduced or whether they were based on objective data. The present study demonstrates that there is a difference between what a clinician may estimate as the amount of lateral joint line opening on physical examination and the actual amount of opening quantified on varus stress radiographs. A review of our objective findings suggests that both the IKDC objective grading score and the referenced American Medical Association grades for lateral compartment opening need to be reconsidered.

The determination of which structures to section and the sequence of individual structure sectioning in our study were determined on the basis of our clinical experience and a study of the available literature. The fibular collateral ligament, popliteus tendon, and popliteofibular ligament together represent the main posterolateral corner structures and have been reported to be the main static stabilizing structures of the posterolateral part of the knee[14,15,27-29]. We chose to section the fibular collateral ligament first because lateral opening of the knee joint does not occur if the fibular collateral ligament is still intact[15,27]. While the cruciate ligaments are not primary varus stabilizers of the knee, we chose to additionally section them after cutting the posterolateral knee structures because they have been demonstrated to be important secondary stabilizers of varus when the posterolateral structures are sectioned[14,15,30,31]. In addition, if the posterolateral structures are cut first, there is a significant increase in the force translated to the cruciate ligaments on varus stress application[9-11,32,33]. Therefore, the decision to additionally section the anterior cruciate ligament and posterior cruciate ligament rests with the recognition that both are known secondary stabilizers to varus stress in the presence of fibular collateral ligament sectioning[14,15,28,34] and additionally with the findings of previous reports that posterolateral knee injuries rarely occur in isolation and most commonly occur with concurrent cruciate ligament injuries[5,6,10,24,29,35].

New techniques for anatomical surgical reconstruction of posterolateral corner injuries have been introduced recently[16,36,37]. For that reason, it is also increasingly important to be able to quantify the extent to which both established and emerging procedures have restored knee stability. We believe that varus stress radiographs are a feasible, cost-effective objective measurement tool for the clinician to document his or her patients' postoperative results and also to allow the results of future research to be more easily compared and understood.

We recognize that the present study had limitations. One limitation was that the tested knees were nonpaired. The values in the present study were derived from simulated injuries of the knee as compared with the intact state and therefore are not the same as those observed in clinical practice, in which the injured knee is compared with the normal, contralateral knee. However, in a study of 100 normal patients, it was reported that the amount of lateral compartment gapping between knees was nearly identical[4], so we believe that it is highly likely that our values reflect the differences that one should observe between an injured and a normal, contralateral knee on varus stress radiographs. In addition, in the clinical situation, especially for acute knee injuries, patient guarding due to pain may mask the amount of lateral compartment gapping on stress radiographs. Finally, only one standardized load condition was applied in each testing state. It is possible that increased amounts of applied loads as compared with our 12-Nm moment may have resulted in lateral compartment gapping closer to the amount found in association with a clinician-applied varus stress. However, it has been noted that some patients do not tolerate more than a 12-Nm moment without pain[22], so applying higher loads with a force-application device may be difficult in some clinical instances because of the increased time that the load is applied to the knee (due to the extra time needed to obtain a stable and accurate load with these devices) as compared with a clinician-applied varus stress, which can be timed with the radiology technician to be performed immediately before a radiograph is made.

In conclusion, the present study demonstrates that the differentiation between isolated fibular collateral ligament and grade-III posterolateral knee injuries can be determined by utilizing varus stress radiographs as an adjunct to a thorough history and physical examination. The findings suggest that one should suspect an isolated fibular collateral ligament tear when varus stress radiographs reveal a side-to-side difference of approximately 2.1 mm in association with a standardized 12-Nm moment or approximately 2.7 mm in association with a clinician-applied varus stress. A grade-III posterolateral corner injury should be suspected when an increase in lateral compartment gapping of approximately 3.4 mm is found in association with a 12-Nm moment or when an increase of approximately 4.0 mm is found in association with a clinician-applied varus stress. Both standardized 12-Nm moments and clinician-applied varus stress radiographs provide objective and reproducible measures of lateral compartment gapping that may be useful for the diagnosis, treatment, and postoperative follow-up of patients who have isolated fibular collateral ligament and posterolateral knee injuries.

Appendix

eA Tables presenting the intraobserver and interobserver intraclass correlation coefficient calculations are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD/DVD (call our subscription department, at 781-449-9780, to order the CD or DVD). ■

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