AJSM PreView, published on July 1, 2010 as doi:10.1177/0363546510370279

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

Warren R. Dunn,[*†] MD, MPH, Kurt P. Spindler,[†] MD, Annunziato Amendola,[‡] MD, Jack T. Andrish,[§] MD, Christopher C. Kaeding,[||] MD, Robert G. Marx,[¶] MD, MSc, Eric C. McCarty,[#] Richard D. Parker,[§] MD, Frank E. Harrell Jr,[†] PhD, Angel Q. An,[†] MS, Rick W. Wright,[**] MD, and the MOON ACL Investigators[††]

From [†]Vanderbilt University Medical School, Nashville, Tennessee, [‡]University of Iowa School of Medicine, Iowa City, Iowa, [§]Cleveland Clinic, Cleveland, Ohio, [||]The Ohio State University School of Medicine, Columbus, Ohio, [¶]Hospital for Special Surgery, New York, New York, [#]University of Colorado School of Medicine, Denver, Colorado, and [**]Washington University School of Medicine at Barnes-Jewish Hospital, St Louis, Missouri

Background: Increased knee pain at the time of anterior cruciate ligament reconstruction may potentially predict more difficult rehabilitation, prolonged recovery, and/or be predictive of increased knee pain at 2 years.

Hypothesis: A bone bruise and/or other preoperative factors are associated with more knee pain/symptoms at the time of index anterior cruciate ligament reconstruction, and the presence of a bone bruise would be associated with specific demographic and injury-related factors.

Study Design: Cohort study (prevalence); Level of evidence, 2.

Methods: In 2007, the Multicenter Orthopaedic Outcomes Network (MOON) database began to prospectively collect surgeon-reported magnetic resonance imaging bone bruise status. A multivariable analysis was performed to (1) determine if a bone bruise, among other preoperative factors, is associated with more knee symptoms/pain and (2) examine the association of factors related to bone bruise. To evaluate the association of a bone bruise with knee pain/symptoms, linear multiple regression models were fit using the continuous scores of the Knee injury and Osteoarthritis Outcome Score (KOOS) symptoms and pain subscales and the Short Form 36 (SF-36) bodily pain subscale as dependent variables. To examine the association between a bone bruise and risk factors, a logistic regression model was used, in which the dependent variable was the presence or absence of a bone bruise.

Results: Baseline data for 525 patients were used for analysis, and a bone bruise was present in 419 (80%). The cohort comprises 58% male patients, with a median age of 23 years. The median Marx activity level was 13. Factors associated with more pain were higher body mass index ($P < .0001$), female sex ($P = .001$), lateral collateral ligament injury ($P = .012$), and older age ($P = .038$). Factors associated with more symptoms were a concomitant lateral collateral ligament injury ($P = .014$), higher body mass index ($P < .0001$), and female sex ($P < .0001$). Bone bruise is not associated with symptoms/pain at the time of index anterior cruciate ligament reconstruction. None of the factors included in the SF-36 bodily pain model were found to be significant. After controlling for other baseline factors, the following factors were associated with a bone bruise: younger age ($P = .034$) and not jumping at the time of injury ($P = .006$).

Conclusion: After anterior cruciate ligament injury, risk factors associated with a bone bruise are younger age and not jumping at the time of injury. Bone bruise is not associated with symptoms/pain at the time of index anterior cruciate ligament reconstruction.

Keywords: bone bruise; ACL reconstruction; KOOS; MOON; knee pain/symptoms

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546510370279

In patients who tear their anterior cruciate ligament (ACL), the consensus of opinion, whether ACL reconstruction (ACLR) or rehabilitation is chosen, is to reduce knee pain and symptoms, activate the quadriceps, normalize range of motion, and promote normal gait.[33] Achieving these parameters is believed to be a prerequisite for appropriate timing of ACLR to reduce risk of arthrofibrosis. Another commonly held belief is that a "bone bruise" (BB) is associated with knee pain after ACL tear. However, in addition to a BB, which is observed in 80% of patients with ACL tears,[8,30,31,34] several demographic, mechanistic, and intra-articular injuries to articular cartilage and meniscus could also be associated with increased knee pain and/or symptoms at ACLR.[3-5,23,31,33] Increased knee pain at the time of ACLR may potentially predict a more difficult rehabilitation, prolonged time to pain-free recovery, and/or be associated with more knee pain at 2 years after ACLR. Identifying whether a BB is associated with knee pain and symptoms could alter preoperative weight-bearing protocols to decrease pain or delay ACLR or to allow sufficient healing time of BB with associated articular cartilage injury.[19,31]

The concomitant BB observed in 80% of ACL tears[30,31,34] predominantly occurs in the lateral femoral condyle and lateral tibial plateau. This BB has been associated with articular cartilage injuries[11,12,19,31,33,34] and meniscal tears.[3,4,23,31,33] Marrow and subchondral injuries observed on MRI have been shown to resolve in a long-term follow-up of a longitudinal cohort.[6,13,29] Magnetic resonance imaging and articular cartilage with bone biopsies of BB have demonstrated articular matrix pathologic changes and chondrocyte and osteocyte cell death.[19] To evaluate which of these concurrent injuries, including the presence of a BB with an ACL tear, are associated with increased knee pain and/or symptoms at the time of ACLR requires multivariable analysis of a large cohort with sufficient sample size to analyze all the aforementioned factors.

Because the BB occurs at the time of injury to the ACL, it may herald other intra-articular injuries that simultaneously occurred. Further, examining the relationship between a BB and patient characteristics such as gender, age, and circumstances of the injury may yield insight into the mechanism of ACL injury.

The goals of this study are to determine if any preoperative factors, including a BB, are associated with knee symptoms and knee pain and to examine the association of baseline factors with the presence of BB occurrences. First, we hypothesized that the presence of a BB would be associated with increased knee pain/symptoms at the time of index ACLR. Second, the presence of a BB would be associated with specific demographic and injury-related factors.

MATERIALS AND METHODS

Study Design and Setting

A multicenter prospective longitudinal cohort design was implemented. In this ongoing Multicenter Orthopaedic Outcomes Network (MOON) cohort study, all patients undergoing ACLR at 7 sites (Cleveland Clinic, The Ohio State University, Hospital for Special Surgery, Washington University at St Louis, University of Iowa, University of Colorado, and Vanderbilt University) by 16 physicians (J.T.A., R.D.P., M.H.J., C.C.K., D.C.F., R.G.M., R.W.W., R.H.B., M.J.M., A.A., B.R.W., E.C.M., M.L.W., A.F.V., K.P.S., and W.R.D.) were targeted for enrollment. The recruitment period for the current study was between December 1, 2006, and July 18, 2008. The comparison for both hypotheses was the initial MRI findings (BB) with preoperative factors that are associated with Knee injury and Osteoarthritis Outcome Score (KOOS) subscales measured at the time of surgery. Except for 16 patients without MRI, all patients met inclusion criteria discussed below.

Participants

Patients having primary ACLR who also had a preoperative MRI performed met inclusion criteria for study. The MOON surgeons prospectively added to surgeon evaluation forms in 2007 whether an MRI was obtained, whether a BB was present, and, if present, the location of BB as lateral femoral condyle (LFC), lateral tibial plateau (LTP), or other. Because a BB is recognizable on multiple types of MRI and the MRI scans were obtained after ACL tears, the surgeons judged appropriateness of timing and reading of the MRI. Participants undergoing primary ACLR without preoperative MRI, as well as revision ACLR, were excluded (Figure 1).

Variables

To test the first hypothesis, that the presence of a BB is associated with knee symptoms and knee pain at the time of ACLR, 3 subscales were used as continuous dependent variables: (1) KOOS pain subscale, (2) KOOS symptoms subscale, and (3) Short Form 36 (SF-36) bodily pain subscale. The KOOS pain subscale includes 9 questions, each scored on a 0 to 4 scale, and the possible raw score

*Address correspondence to Warren R. Dunn, MD, MPH, Department of Orthopaedic Surgery and Rehabilitation, Vanderbilt University Medical School, Nashville, TN 37232-8300 (e-mail: warren.dunn@vanderbilt.edu).

††Robert H. Brophy, MD, Matthew J. Matava, MD, Washington University School of Medicine at Barnes-Jewish Hospital; David C. Flanigan, MD, The Ohio State University School of Medicine; Laura J. Huston, MS, Vanderbilt University Medical School; Morgan H. Jones, MD, MPH, Cleveland Clinic; Michelle L. Wolcott, MD, Armando F. Vidal, MD, University of Colorado School of Medicine; and Brian R. Wolf, MD, MS, University of Iowa School of Medicine.

Presented at 35th annual meeting of the AOSSM, Keystone, Colorado, July 2009.

One or more authors has declared a potential conflict of interest: This project was supported in part by NIH grants No. K23 AR052392-04 (Dr Dunn) and 1R01 AR053684 (Dr Spindler), an AOSSM-MTF Career Development Award Supplement (Dr Dunn), and the Vanderbilt Sports Medicine Research Fund. Unrestricted educational grants were also provided by DonJoy and Smith & Nephew Endoscopy. Dr Brophy is a paid consultant (less than $10000) for DePuy Mitek.

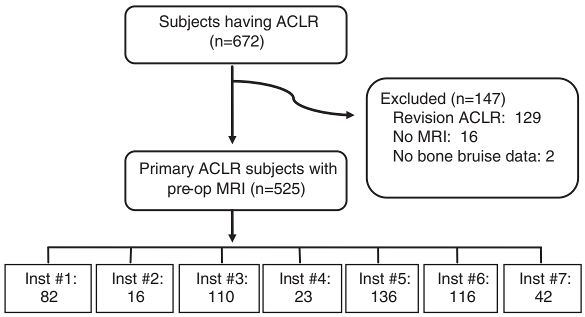

Figure 1. Study flow diagram: Multicenter Orthopaedic Outcomes Network anterior cruciate ligament reconstruction cohort.

ranging from 0 to 36 is transformed to a 0 to 100 score, where 100 constitutes no pain and 0 is the worst score.[28] The KOOS symptoms subscale consists of 7 questions scored on a 0 to 4 scale, and the possible raw scores ranging from 0 to 28 are transformed into a 0 to 100 score where 100 is the best score and 0 is the worst. The bodily pain subscale of the SF-36 contains 2 items; 1 has 6 levels of responses, and the other has 5, which is recoded to a 6-level item and transformed into a 0 to 100 score where 100 is the best health and 0 is the worst.[18] The presence of a BB was captured as a discrete (yes/no) variable, and location was recorded as a nominal variable with 4 categories: none, LTP, LFC, and other. The grading of the Lachman, medial collateral ligament (MCL), and lateral collateral ligament (LCL) was performed by each surgeon at the time of ACLR and they were classified according to International Knee Documentation Committee (IKDC) criteria. For the first hypothesis (whether a BB is associated with knee symptoms or pain), a BB was considered as an exposure (independent variable); however, for our second hypothesis (association of a BB with demographics and intra-articular injuries), BB was treated as the outcome (dependent variable). Tables 1 and 2 include the exposures and potential confounders included in our analyses stratified by BB status.

Data Sources and Measurement

After documentation of informed consent, participants completed a 13-page questionnaire examining self-reported demographics, injury characteristics, sports participation history, comorbidities, and health status. Regarding the latter, the following validated instruments are included: SF-36 (version 2), the KOOS, which includes the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and the Marx activity scale. This is administered on the day of surgery, and completed within 2 weeks of the surgery date.

The KOOS was developed as a patient-based assessment tool to evaluate sports injuries (ACL injuries, meniscal tears, and mild osteoarthritis) in young and middle-aged athletes as an extension of the WOMAC.[26,28] The outcome instrument is composed of 42 questions covering 5 subscales: pain (9 items), symptoms (7 items), activities of daily living (17 items), sport and recreation function (5 items), and knee-related quality of life (4 items).[28] Each subscale is summed and transformed to a 0 (worst possible) to 100 (best possible) score. The KOOS has undergone extensive validation for the assessment of ACL injuries, meniscectomies, tibial osteotomies, and posttraumatic osteoarthritis.[10,25,27,28,35] A change in score of 8 points represents a real change in condition.[26] The minimum clinically important difference for SF-36 is reported to be 12% (12 points) over the transformed 100-point scale score.[1]

The Marx activity scale was developed as a short, patient-reported activity assessment that estimates the peak activity over the past year to account for variability related to seasonal trends in sports or injury.[21] It is a validated tool that quantifies the frequency of running, cutting, decelerating, and pivoting activities, which are difficult for those with ACL deficiency. It contains 4 items that ask about frequency of participation in running, cutting, decelerating, and pivoting; items are scored using a 5-point scale quantifying the frequency of participation in each activity—less than 1 time per month (0), 1 time per month (1), 1 time per week (2), 2 or 3 times per week (3), and 4 or more times in a week (4). The metric is reported as the sum of scores from the 4 categories ranging from 0 to 16. For example, a young, competitive, high school athlete practicing 4 times per week in football, basketball, or soccer would score a 16. Conversely, a recreational jogger running 3 times per week would score a 3.

After ACLR, surgeons complete a 49-page questionnaire that includes sections on history of knee injury and/or surgery on both knees, the results of the general knee examination done under anesthesia, recording of all intra-articular injuries and treatments to the meniscus and articular cartilage, and the surgical technique used for the ACLR. Classification of the general knee examination findings follows the recommendations of the updated 1999 IKDC guidelines.[16,17] Surgeon documentation of articular cartilage injury is recorded on the modified Outerbridge classification.[7,20] Meniscal injuries are classified by size, location, and partial versus complete tears, and treatment is recorded as not treated, repair, or extent of resection.[9]

Completed data forms are mailed from the participating sites to the data coordinating center. Data from both the patient and surgeon questionnaires are scanned with Teleform software (Cardiff Software, Inc, Vista, California) using optical character recognition to avoid manual data entry, and the scanned data are verified and then exported to a database.[14,24] Both patient and surgeon questionnaires have a matched, barcode unique identification on each page to de-identify the data and to aid in data merging.

Study Size

Sample size considerations guided variable selection to generate a model as complex as the data would allow without overfitting the data using the ratio $m/10$ as the

TABLE 1
Patient Characteristics by Bone Bruise Status[a]

	N	No (N = 106)	Yes (N = 419)	Combined (N = 525)
Injury chronicity, wk	265	9.1 **20.4** 41.0 (74.7 ± 170.2)	4.3 **8.3** 14.1 (37.6 ± 136.7)	4.6 **9.3** 20.4 (44.5 ± 143.8)
Pain chronicity, wk	352	5.7 **14.9** 26.7 (54.0 ± 154.3)	4.3 **7.3** 12.6 (16.9 ± 65.2)	4.4 **7.9** 14.1 (22.9 ± 86.9)
Giving way episodes	439	2.0 **4.0** 10.0 (11.5 ± 20.3)	1.0 **2.0** 5.0 (5.2 ± 9.9)	1.0 **3.0** 6.0 (6.6 ± 13.1)
Reinjuries	440	0.0 **1.0** 2.0 (3.0 ± 9.3)	0.0 **0.0** 1.0 (0.8 ± 2.2)	0.0 **0.0** 1.0 (1.3 ± 4.8)
Sex	525			
Male		60% (64/106)	57% (240/419)	58% (304/525)
Female		40% (42/106)	43% (179/419)	42% (221/525)
Age, y	525	19 **30** 41 (31 ± 13)	17 **22** 32 (25 ± 11)	17 **23** 34 (26 ± 11)
Baseline BMI	525	23.0 **26.1** 29.5 (27.1 ± 5.8)	22.1 **24.4** 27.6 (25.6 ± 5.5)	22.1 **24.8** 28.0 (25.9 ± 5.6)
Activity at injury	465			
Baseball/softball		2% (2/101)	4% (16/364)	4% (18/465)
Basketball		14% (14/101)	20% (73/364)	19% (87/465)
Football		8% (8/101)	18% (66/364)	16% (74/465)
Other sport		24% (24/101)	21% (78/364)	22% (102/465)
Skiing		9% (9/101)	7% (26/364)	8% (35/465)
Soccer		16% (16/101)	16% (60/364)	16% (76/465)
Non-sport		28% (28/101)	12% (45/364)	16% (73/465)
Contact injury	525			
No		83% (88/106)	72% (302/419)	74% (390/525)
Yes		17% (18/106)	28% (117/419)	26% (135/525)
"Pop" at injury	525			
No		29% (31/106)	34% (141/419)	33% (172/525)
Yes		71% (75/106)	66% (278/419)	67% (353/525)
Injured jumping	525			
No		65% (69/106)	76% (319/419)	74% (388/525)
Yes		35% (37/106)	24% (100/419)	26% (137/525)
Marx activity score	521	4.0 **12.0** 16.0 (9.6 ± 5.8)	10.0 **14.0** 16.0 (12.3 ± 4.8)	9.0 **13.0** 16.0 (11.7 ± 5.1)
KOOS pain	521	53 **75** 83 (68 ± 20)	56 **72** 83 (70 ± 19)	56 **72** 83 (69 ± 19)
KOOS symptoms	519	50 **68** 82 (65 ± 20)	50 **64** 79 (63 ± 19)	50 **64** 79 (64 ± 19)
SF-36 bodily pain	523	42.0 **44.0** 51.0 (44.3 ± 8.9)	41.0 **44.0** 52.0 (45.7 ± 10.2)	41.0 **44.0** 52.0 (45.4 ± 10.0)

[a]The 3 values a **b** c represent the lower quartile a, the median **b**, and the upper quartile c. This means that 25% of the scores are either below (<lower quartile) or above (>higher quartile). The number in parentheses is the mean ± 1 standard deviation. N represents the number of non-missing values.

BMI, body mass index; KOOS, Knee injury and Osteoarthritis Outcome Score; SF-36, Short Form 36.

minimum acceptable ratio for reliable models. Hence, sample size estimates are based on model complexity where m is the effective sample and $m/10$ parameters (predictors plus nonlinearities and interactions) are possible in the model.[15] The effective sample size to model the presence of a BB as the dependent variable equals 106 (the number of participants without a BB).

Quantitative Variables and Statistical Methods

The following categorical variables were reduced because of low prevalence categories. Articular cartilage variables were grouped by compartment (medial, lateral, anterior), and severity of chondromalacia was dichotomized into grade II chondromalacia or higher being positive for chondrosis in that compartment. Activities at injury variables were collapsed into a new variable with 3 levels: non-sport injury (n = 73), contact sport injury (football, n = 74), and noncontact sport injury (n = 318). The latter, noncontact sport injuries, included athletes injured playing baseball/softball (n = 18), basketball (n = 87), soccer (n = 76), skiing (n = 35), and other sports (n = 102). Lateral collateral ligament injury was less common than MCL injury and was dichotomized into normal and abnormal (n = 14). The MCL injuries were collapsed into a 3-level variable: normal, grade I (n = 23), and grades II/III (n = 24).

To evaluate the association of a BB with knee pain and symptoms (hypothesis 1), multivariable linear multiple regression models were fit using the continuous scores of the KOOS symptoms subscale, KOOS pain subscale, and the SF-36 bodily pain subscale as the dependent variable. Independent variables included in these models were age, sex, body mass index (BMI), injury chronicity, medial meniscus status and treatment, lateral meniscus status and treatment, collateral ligament injury, laxity by Lachman examination, and chondrosis in the medial, lateral, and anterior compartments.

To examine the association between a BB and risk factors (hypothesis 2), a logistic regression model was used in which the dependent variable was the presence or absence of a BB, and independent variables were age, BMI, sex, contact injury, jumping at the time of injury,

TABLE 2
Intra-articular Factors by Bone Bruise Status[a]

	No (N = 106)		Yes (N = 419)		Combined (N = 525)	
Chondrosis lateral compartment						
No	81%	86/106	75%	314/419	76%	400/525
Yes	19%	20/106	25%	105/419	24%	125/525
Anterior compartment chondrosis						
No	75%	80/106	83%	347/419	81%	427/525
Yes	25%	26/106	17%	72/419	19%	98/525
Medial compartment chondrosis						
No	70%	74/106	79%	329/419	77%	403/525
Yes	30%	32/106	21%	90/419	23%	122/525
Medial meniscus status						
≤50% excision	26%	28/106	8%	34/419	12%	62/525
>50% or complete excision	8%	9/106	3%	11/419	4%	20/525
Normal	51%	54/106	63%	264/419	61%	318/525
Repair	11%	12/106	19%	80/419	18%	92/525
Tear not treated	3%	3/106	7%	30/419	6%	33/525
Lateral meniscus status						
≤50% excision	23%	24/106	25%	105/419	25%	129/525
>50% or complete excision	2%	2/106	2%	10/419	2%	12/525
Normal	60%	64/106	52%	216/419	53%	280/525
Repair	6%	6/106	8%	34/419	8%	40/525
Tear not treated	9%	10/106	13%	54/419	12%	64/525
Lachman						
<5 mm SSD	22%	23/106	24%	102/419	24%	125/525
6-10 mm SSD	52%	55/106	61%	254/419	59%	309/525
>10 mm SSD	26%	28/106	15%	63/419	17%	91/525

[a]SSD, side-to-side difference.

a "pop" at time of injury, activity at injury, and the Marx activity score.

We did not assume linearity of covariate effects but only assumed smoothed relationships, using restricted cubic regression splines. Missing values of predictor variables were imputed using multiple imputation incorporating predictive mean matching and flexible additive imputation models as implemented in the *aregImpute* function available in the Hmisc package in R statistical software.[2] Data reduction methods used to preserve degrees of freedom in models included pooling of low prevalence categories, variable grouping, and hierarchical clustering (using squared Spearman rank correlation coefficients as the similarity matrix) to identify colinear variables that could be deleted from the model. Statistical analysis was performed with free open-source R statistical software (www. r-project.org).

RESULTS

There were 672 patients undergoing ACLR with baseline data collected between December 1, 2006 and July 18, 2008 examined for eligibility, and 129 revision cases were excluded. Of the remaining 543 primary cases, 525 were confirmed eligible and analyzed (Figure 1). Patient characteristics including KOOS subscales and the SF-36 bodily pain subscale are listed in Table 1 stratified by BB status. Intra-articular findings and results of the Lachman examination are listed in Table 2, stratified by BB status.

Risk Factors Associated With Knee Pain and Symptoms on the KOOS

The presence of a BB as yes/no or by location was not associated with knee pain/symptoms as measured by the KOOS pain and symptoms subscales, nor the SF-36 bodily pain subscale. Factors associated with having more pain on the KOOS subscale were higher BMI ($P < .0001$), female sex ($P = .001$), an LCL injury ($P = .012$), and older age ($P = .038$), which are adjusted for injury chronicity, medial meniscus status and treatment, lateral meniscus status and treatment, laxity by Lachman examination, MCL injury, and chondrosis in the medial, lateral, and anterior compartments (Figure 2). The presence of chondrosis in the anterior compartment was associated with less pain ($P = .031$). A summary of effects is given in Appendix I (see online Appendix for this article at http://ajs.sagepub.com/supplemental/), using interquartile ranges (IQRs) for continuous variables with the 95% confidence intervals (CIs) for the mean effects, which are plotted in Figure 2. A partial effects plot is shown in Appendix II (see online Appendix for this article at http://ajs.sagepub.com/supplemental/). The presence of an LCL injury was associated with both a statistically and clinically meaningful increase in pain with a mean effect of –14.1 (95%CI: –25.2,

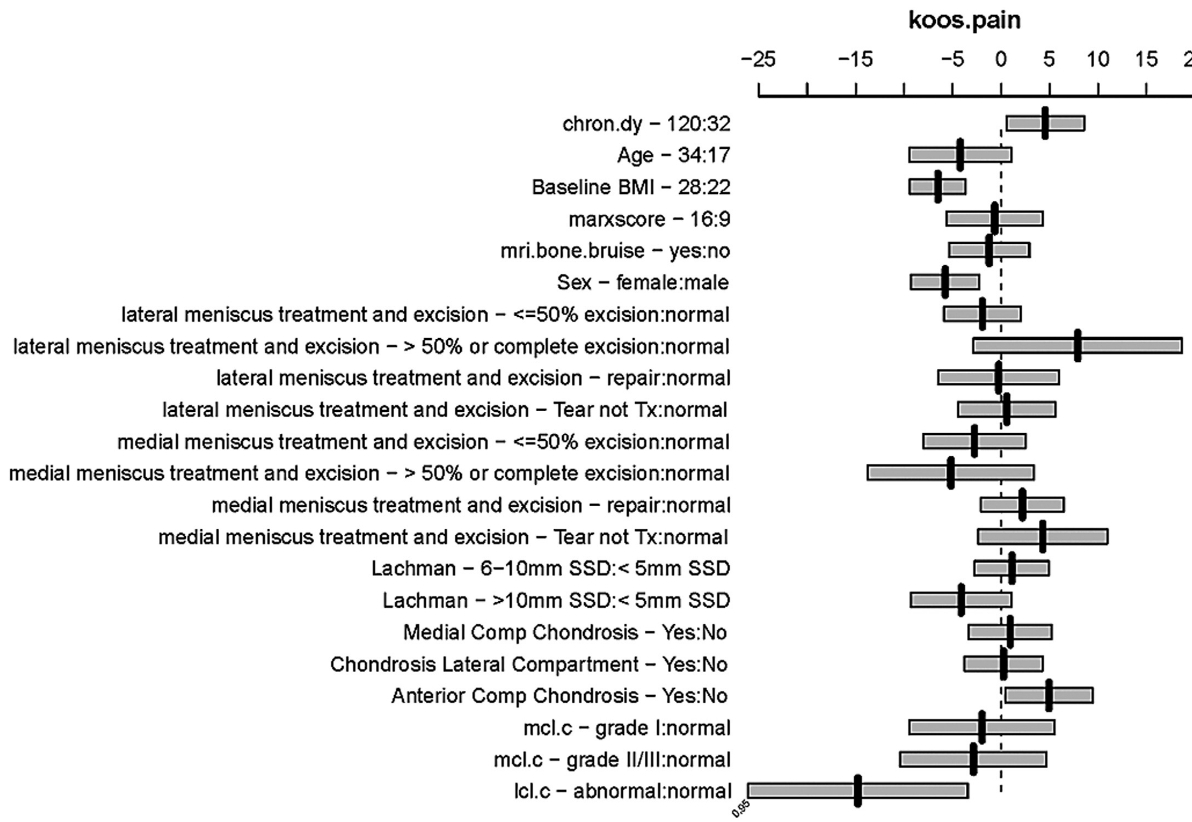

Figure 2. Plot of effects of predictors in the model for Knee injury and Osteoarthritis Outcome Score (KOOS) pain subscale using interquartile ranges for continuous variables with bars representing the 95% confidence interval for the mean effect. For example, the effect of raising body mass index (BMI) from its first quartile (22) to its third quartile (28) is to lower the mean KOOS pain score by 6.5 points. For the KOOS pain subscale, a score of 100 indicates normal without pain whereas a score of 0 indicates the worst pain. Thus, lowering the KOOS pain score indicates an increase in pain. chron.dy, chronicity in days; SSD, side-to-side difference; mcl.c, medial collateral ligament; lcl.c, lateral collateral ligament.

–3.0). Although sex, age, and BMI were statistically significant, none of the respective point estimates (–5.9, –4.1, and –6.5) represents a clinically meaningful difference (8 points). Using the nomogram in Figure 3, one can estimate the cumulative effects of these predictors. For instance, letting the other variables default to the value of category contributing no points to the total (left-most value/category), summing the points for a male with a BMI of 20 (~10 points for male + 89 for BMI = 99 total points) compared with a female with BMI of 25 (0 points for female + ~78 for BMI = 78 total points), the predicted KOOS pain scores are 43 and 30, respectively, which would be considered a clinically meaningful difference.

Factors associated with having more symptoms on the KOOS subscale were a concomitant LCL injury (P = .014), higher BMI ($P < .0001$), and female sex ($P < 0.0001$), which are adjusted for age, injury chronicity, medial meniscus status and treatment, lateral meniscus status and treatment, MCL injury, laxity by Lachman examination, and chondrosis in the medial, lateral, and anterior compartments. A summary of effects is given in Appendix III (see online Appendix for this article at http://ajs.sagepub.com/supplemental/), using IQR for continuous variables with the 95% CIs for the mean effects, which are plotted in Figure 4. The presence of an LCL injury was associated with both a statistically and clinically meaningful increase in symptoms with a mean effect of -12.4 (95%CI: –22.2, –2.6). While sex and BMI were statistically significant, the respective point estimates (–6.9 and –7.4) do not represent a clinically meaningful difference on the KOOS. However, using the nomogram in Figure 5, one can estimate the cumulative effects of the predictors on symptoms. For instance, summing the points for a 20-year-old male with a BMI of 20 and a normal LCL (~14 points for male + ~10 points for age + 23 points for LCL + 87 for BMI = 134 total points) compared with a 20-year-old female with a BMI of 25 and a normal LCL (0 points for female + 10 points for age + 23 points for LCL + ~75 for BMI = 108 total points), the predicted KOOS symptoms scores are 51 and 36, respectively, which would be considered a clinically meaningful difference.

None of the factors included in the SF-36 bodily pain model were found to be significant; the summary effects

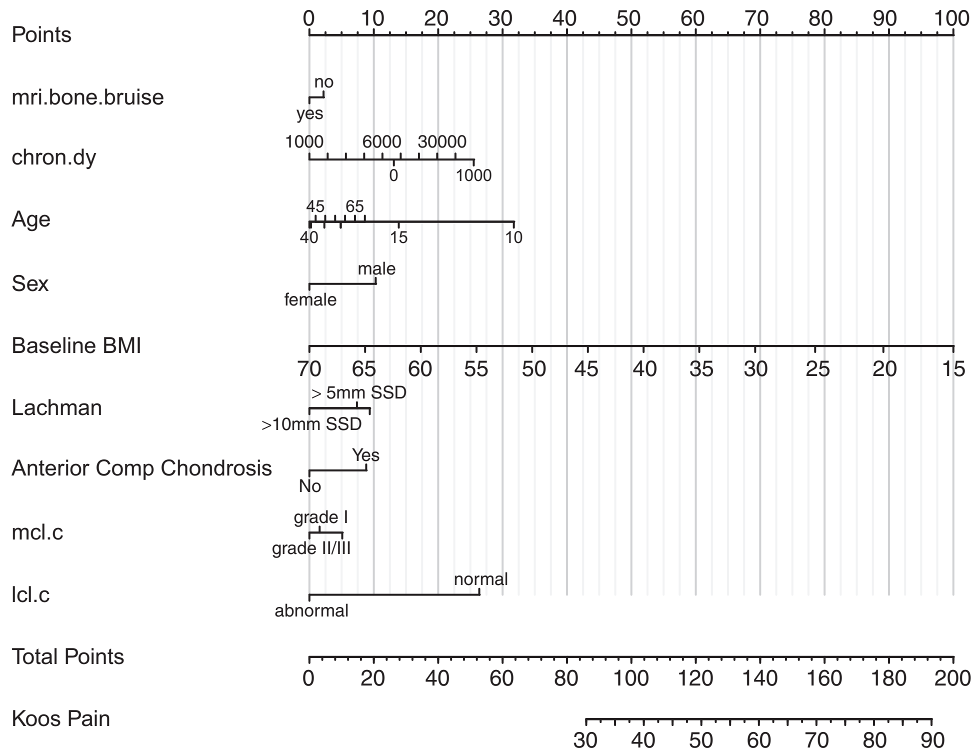

Figure 3. Nomogram for model predicting Knee injury and Osteoarthritis Outcome Score (KOOS) pain scores. The nomogram is used to predict an individual patient's KOOS score as follows. First, each variable is marked and the points for each are derived by viewing the point total on the top of the nomogram. Then the points are totaled and placed on the bottom total points scale. After placing the total points, view down to obtain the KOOS subscale score.

are listed in Appendix IV, and plotted in Appendix V (see online Appendix for this article at http://ajs.sagepub.com/supplemental/).

Risk Factors Associated With a Bone Bruise

The number of parameters included in the model examining risk factors associated with a BB was limited by the effective sample size (106). Hence, to reduce the degrees of freedom to 10, 8 variables considered to be the most relevant were included in the model, which were age, BMI, sex, contact injury, jumping at the time of injury, a "pop" at time of injury, activity at injury, and the Marx activity score. Factors associated with having a BB were younger age (P = .034) and not jumping at the time of injury (P = .006). A table including the point estimates for each parameter is provided in Appendix VI (see online Appendix for this article at http://ajs.sagepub.com/supplemental/), and Figure 6 is a plot of the odds ratios from the final model.

DISCUSSION

The results of all 3 validated, patient-reported outcome scales (KOOS pain, KOOS symptoms, SF-36 bodily pain) refute our first hypothesis that a BB is associated with pain or symptoms at index ACLR. To our knowledge, this is the first multivariable modeling to include the majority of "knee injuries," which occur concurrently at ACL injury and are plausible sources of pain/symptoms. However, after adjusting for demographic and mechanistic factors, as well as meniscal and articular cartilage injuries, only concomitant LCL injury was both statistically significant and clinically relevant. The finding of chondrosis in the anterior compartment being associated with less pain, mean effect of 5.02 (95% CI: 0.49, 9.55), does not have an obvious clinical or biological explanation. Alternative explanations include Type I error and an unmeasured third variable that is associated with anterior chondrosis and knee pain. Other plausible variables not examined in the current study, such as cytokines and neurogenic chemical pain mediators, could be explored in future research. Higher BMI and female sex are associated with increased pain and symptoms, and for the clinician, the nomogram can be used to calculate the expected pain and symptoms at ACLR for an individual patient.

For the second hypothesis, both younger age and not jumping at the time of injury were significantly associated with the presence of a BB, while gender, Marx activity level, BMI, and other mechanistic factors were not. A prior prospective study likewise found a significant association

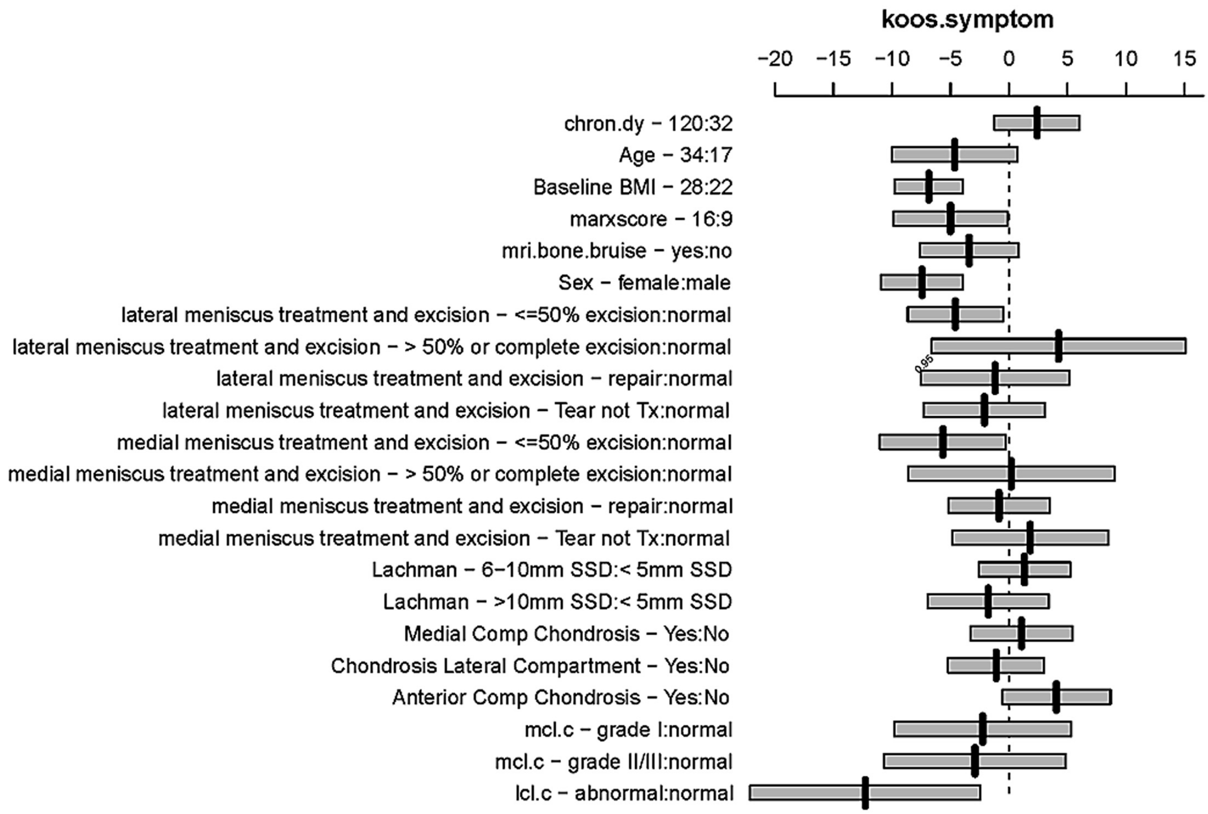

Figure 4. Plot of effects of predictors in the model for Knee injury and Osteoarthritis Outcome Score (KOOS) symptoms subscale using interquartile ranges for continuous variables with bars representing the 95% confidence interval for the mean effect. For example, the effect of raising body mass index (BMI) from its first quartile (22) to its third quartile (28) is to lower the mean KOOS symptoms score by 7 points. For the KOOS symptoms subscale, a score of 100 indicates normal without symptoms and a score of 0 indicates the worst symptoms. Thus, lowering the KOOS symptom score indicates an increase in symptoms. chron.dy, chronicity in days; SSD, side-to-side difference; mcl.c, medial collateral ligament; lcl.c, lateral collateral ligament.

between jumping and a BB.[31] At 12-year follow-up of this cohort, all the BB marrow changes had resolved, and there was no difference in IKDC scores among those with and without a BB at index.[13]

There are several study limitations. Foremost is inherent to the cross-sectional design using only baseline data from a prospective cohort; hence, causal inferences cannot be made. Two-year follow-up of this cohort is planned to determine the relationship between the presence of a BB on MRI and outcomes after ACLR. Temporal trends that are difficult to account for may influence pain and symptoms. For instance, a BB could be a cause of symptoms after the initial injury and then resolve with time before index ACLR. To that end, the standard clinical guideline followed by the MOON group (regain active range of motion, quadriceps function, and normal gait as a prerequisite to perform ACLR)[33] likely introduces some lag time. Patients at the time of index ACLR still have clinically relevant levels of pain and symptoms as reflected in their baseline scores. Regarding our second hypothesis, the model was limited by the effective sample size of 106 patients without a BB; consequently, only 8 variables were examined. Rationale for inclusion of these parameters is based both on clinical knowledge and existing evidence.[5,22,23,32] The multicenter design (7 sites and 16 surgeons) and large sample size (N = 525) seem generalizable to fellowship-trained sports medicine doctors in an academic setting and, potentially, to a broader population of ACL tears.

In the short-term, the presence of a BB on MRI concurrent with an ACL tear is not associated with patient-reported outcomes of pain and symptoms at time of index ACLR; patients with higher BMI and females report more pain and symptoms. The key findings of the study are presented in nomograms, which have several advantages, including ease of interpretation compared to regression equations, and they can be used to calculate knee pain and symptoms for individual patients. Finally, the presence of a BB is associated with younger age and not jumping at the time of injury. Future planned 2-year follow-up

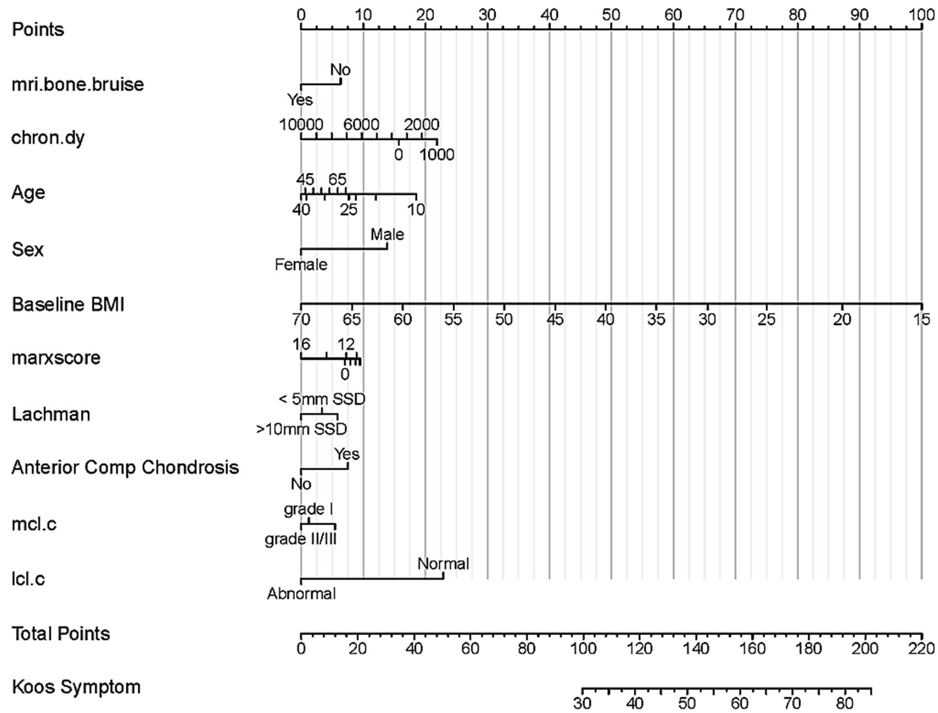

Figure 5. Nomogram for model predicting Knee injury and Osteoarthritis Outcome Score (KOOS) symptoms score. The nomogram is used to predict an individual patient's KOOS score as follows. First, each variable is marked and the points for each are derived by viewing the point total on the top of the nomogram. Then the points are totaled and placed on the bottom total points scale. After placing the total points, view down to obtain KOOS subscale score.

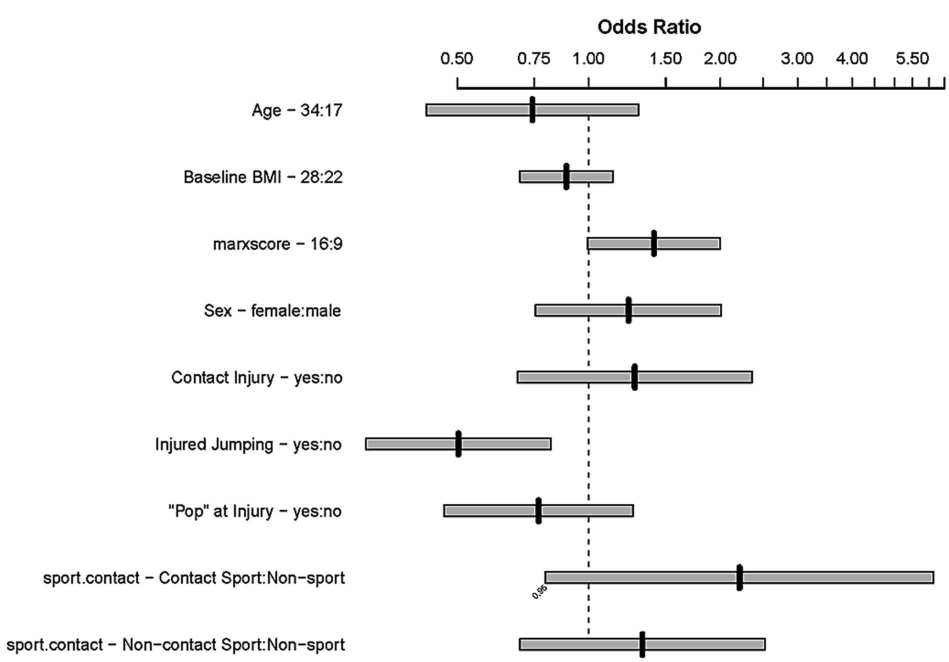

Figure 6. Association of risk factors with having a bone bruise.

of this cohort will evaluate the relationship between a BB and patient-reported outcomes after ACLR.

REFERENCES

1. Angst F, Aeschlimann A, Stucki G. Smallest detectable and minimal clinically important differences of rehabilitation intervention with their implications for required sample sizes using WOMAC and SF-36 quality of life measurement instruments in patients with osteoarthritis of the lower extremities. *Arthritis Rheum*. 2001;45(4):384-391.
2. Baigent C, Harrell FE, Buyse M, Emberson JR, Altman DG. Ensuring trial validity by data quality assurance and diversification of monitoring methods. *Clin Trials*. 2008;5(1):49-55.
3. Beynnon BD, Johnson RJ, Abate JA, Fleming BC, Nichols CE. Treatment of anterior cruciate ligament injuries, part 2. *Am J Sports Med*. 2005;33(11):1751-1767.
4. Beynnon BD, Johnson RJ, Abate JA, Fleming BC, Nichols CE. Treatment of anterior cruciate ligament injuries, part 1. *Am J Sports Med*. 2005;33(10):1579-1602.
5. Bowers AL, Spindler KP, McCarty EC, Arrigain S. Height, weight, and BMI predict intra-articular injuries observed during ACL reconstruction: evaluation of 456 cases from a prospective ACL database. *Clin J Sport Med*. 2005;15(1):9-13.
6. Costa-Paz M, Muscolo DL, Ayerza M, Makino A, Aponte-Tinao L. Magnetic resonance imaging follow-up study of bone bruises associated with anterior cruciate ligament ruptures. *Arthroscopy*. 2001; 17(5):445-449.
7. Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: a review of 31,516 knee arthroscopies. *Arthroscopy*. 1997;13(4):456-460.
8. Davies NH, Niall D, King LJ, Lavelle J, Healy JC. Magnetic resonance imaging of bone bruising in the acutely injured knee—short-term outcome. *Clin Radiol*. 2004;59(5):439-445.
9. Dunn WR, Wolf BR, Amendola A, et al. Multirater agreement of arthroscopic meniscal lesions. *Am J Sports Med*. 2004;32(8): 1937-1940.
10. Englund M, Roos EM, Lohmander LS. Impact of type of meniscal tear on radiographic and symptomatic knee osteoarthritis: a sixteen-year followup of meniscectomy with matched controls. *Arthritis Rheum*. 2003;48(8):2178-2187.
11. Faber KJ, Dill JR, Amendola A, Thain L, Spouge A, Fowler PJ. Occult osteochondral lesions after anterior cruciate ligament rupture: six-year magnetic resonance imaging follow-up study. *Am J Sports Med*. 1999;27(4):489-494.
12. Fang C, Johnson D, Leslie MP, Carlson CS, Robbins M, Di Cesare PE. Tissue distribution and measurement of cartilage oligomeric matrix protein in patients with magnetic resonance imaging-detected bone bruises after acute anterior cruciate ligament tears. *J Orthop Res*. 2001;19(4):634-641.
13. Hanypsiak BT, Spindler KP, Rothrock CR, et al. Twelve-year follow-up on anterior cruciate ligament reconstruction: long-term outcomes of prospectively studied osseous and articular injuries. *Am J Sports Med*. 2008;36(4):671-677.
14. Hardin JM, Woodby LL, Crawford MA, Windsor RA, Miller TM. Data collection in a multisite project: Teleform. *Public Health Nurs*. 2005;22(4):366-370.
15. Harrell FE Jr. *Regression Modeling Strategies*. New York: Springer; 2001.
16. 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.
17. Irrgang JJ, Ho H, Harner CD, Fu FH. Use of the International Knee Documentation Committee guidelines to assess outcome following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 1998;6(2):107-114.
18. John E, Ware J, Kosiniski M, Dewey JE. *How to Score Version 2 of the SF-36 Health Survey*. Lincoln, RI: Quality Metric Incorporated; 2000.
19. Johnson DL, Urban WP Jr, Caborn DN, Vanarthos WJ, Carlson CS. Articular cartilage changes seen with magnetic resonance imaging-detected bone bruises associated with acute anterior cruciate ligament rupture. *Am J Sports Med*. 1998;26(3):409-414.
20. Marx RG, Connor J, Lyman S, et al. Multirater agreement of arthroscopic grading of knee articular cartilage. *Am J Sports Med*. 2005;33(11):1654-1657.
21. Marx RG, Stump TJ, Jones EC, Wickiewicz TL, Warren RF. Development and evaluation of an activity rating scale for disorders of the knee. *Am J Sports Med*. 2001;29(2):213-218.
22. Paul JJ, Spindler KP, Andrish JT, Parker RD, Secic M, Bergfeld JA. Jumping versus nonjumping anterior cruciate ligament injuries: a comparison of pathology. *Clin J Sport Med*. 2003;13(1):1-5.
23. Piasecki DP, Spindler KP, Warren TA, Andrish JT, Parker RD. Intraarticular injuries associated with anterior cruciate ligament tear: findings at ligament reconstruction in high school and recreational athletes: an analysis of sex-based differences. *Am J Sports Med*. 2003;31(4):601-605.
24. Quan KH, Vigano A, Fainsinger RL. Evaluation of a data collection tool (TELEform) for palliative care research. *J Palliat Med*. 2003; 6(3):401-408.
25. Roos E. Rigorous statistical reliability, validity, and responsiveness testing of the Cincinnati Knee Rating System in 350 subjects with uninjured, injured, or anterior cruciate ligament-reconstructed knee. *Am J Sports Med*. 2000;28(3):436-438.
26. Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): from joint injury to osteoarthritis. *Health Qual Life Outcomes*. 2003;1:64.
27. Roos EM, Ostenberg A, Roos H, Ekdahl C, Lohmander LS. Long-term outcome of meniscectomy: symptoms, function, and performance tests in patients with or without radiographic osteoarthritis compared to matched controls. *Osteoarthritis Cartilage*. 2001; 9(4):316-324.
28. 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.
29. Rosen MA, Jackson DW, Berger PE. Occult osseous lesions documented by magnetic resonance imaging associated with anterior cruciate ligament ruptures. *Arthroscopy*. 1991;7(1):45-51.
30. Speer KP, Spritzer CE, Bassett FH 3rd, Feagin JA Jr, Garrett WE Jr. Osseous injury associated with acute tears of the anterior cruciate ligament. *Am J Sports Med*. 1992;20(4):382-389.
31. Spindler KP, Schils JP, Bergfeld JA, et al. Prospective study of osseous, articular, and meniscal lesions in recent anterior cruciate ligament tears by magnetic resonance imaging and arthroscopy. *Am J Sports Med*. 1993;21(4):551-557.
32. Spindler KP, Warren TA, Callison JC Jr, Secic M, Fleisch SB, Wright RW. Clinical outcome at a minimum of five years after reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am*. 2005; 87(8):1673-1679.
33. Spindler KP, Wright RW. Clinical practice: anterior cruciate ligament tear. *N Engl J Med*. 2008;359(20):2135-2142.
34. Vellet AD, Marks PH, Fowler PJ, Munro TG. Occult posttraumatic osteochondral lesions of the knee: prevalence, classification, and short-term sequelae evaluated with MR imaging. *Radiology*. 1991; 178(1):271-276.
35. W-Dahl A, Toksvig-Larsen S, Roos EM. A 2-year prospective study of patient-relevant outcomes in patients operated on for knee osteoarthritis with tibial osteotomy. *BMC Musculoskelet Disord*. 2005;6:18.