

A Simple Clinical Predictive Model for Arthroscopic Mobility of Osteochondritis Dissecans Lesions of the Knee

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Background: Osteochondritis dissecans (OCD) of the knee is a focal idiopathic alteration of subchondral bone and/or its precursor with risk for instability and disruption of adjacent cartilage. Treatment options focused on preventing premature osteoarthritis vary depending on multiple patient and lesion characteristics, including lesion mobility.

Purpose: To differentiate lesion mobility before arthroscopy using a multivariable model that includes patient demographic characteristics and physical examination findings.

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

Methods: Demographic, preoperative physical examination, and radiographic data were collected from a multicenter national prospective cohort of patients with OCD of the knee. Inclusion criteria included patients ≥ 9 years of age and patients with arthroscopically confirmed mobility status based on the Research on Osteochondritis Dissecans of the Knee arthroscopy classification. Multivariable logistic regression analysis using stepwise model selection was used to determine factors associated with the likelihood of a mobile versus an immobile lesion. A 75% partition of the data was used for model training, and 25% was used as a validation cohort. Quantitative model fit statistics were computed using the holdout data, including sensitivity, specificity, and the area under the receiver operating characteristic curve (AUC), along with the corresponding 95% CI.

Results: A total of 407 patients in the prospective cohort met inclusion criteria, and 62% were male. The mean $\pm$ SD age was 13.7 ± 2.2 years, height 161.8 ± 5.3 cm, and weight 59.2 ± 42.2 kg. Arthroscopic evaluation yielded 235 immobile and 172 mobile lesions. Multivariable analysis determined that the best model to predict lesion mobility included chronologic age ≥ 14 years ($P = .001$), effusion on physical examination ($P = .001$), and any loss of range of motion on physical examination ($P = .07$), while controlling for male sex ($P = .38$) and weight ≥ 54.4 kg ($P = .12$). In the 25% holdout validation sample ($n = 102$), a sensitivity of 83%, a specificity of 82%, and an AUC of 0.89 (95% CI, 0.82-0.95) were achieved with these predictive factors.

Conclusion: Age, effusion, and loss of motion can predict knee OCD lesion mobility at the time of arthroscopy. Education about lesion mobility can help with surgical planning and patient and family counseling.

Keywords: osteochondritis dissecans; OCD; arthroscopy; ROCK Group; knee

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Osteochondritis dissecans (OCD) of the knee is a focal idiopathic alteration of subchondral bone and its precursors, with risk for instability and disruption of adjacent articular cartilage that may result in premature osteoarthritis.⁵ Juvenile OCD is a relatively uncommon pathology with an incidence of about 9.5 per 100,000 children and adolescents. It primarily affects those between the ages of 12 and 19 years.^{3,4,9} OCD most commonly affects the knee but can also be found in the elbow and ankle.³ OCD is considered idiopathic in nature, but proposed causative factors can include vascular disruption, trauma, and genetic predisposition.^{3,4,6,13} The most current data suggest that OCD occurs secondary to vascular disruption in the epiphyseal growth cartilage, although how or why the vascular disruption occurs is yet to be delineated and may be related to factors such as trauma, mechanical

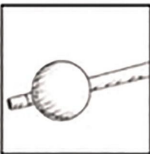
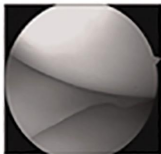
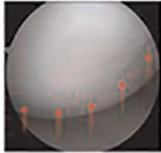
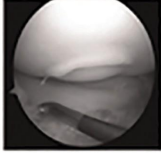
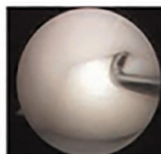
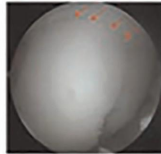
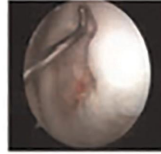
	Type and Description	Diagrams		
Immobile Lesions	Cue ball: No abnormality detectable arthroscopically.			
	Shadow: Cartilage is intact and subtly demarcated (possibly under low light).			
	Wrinkle in the rug: Cartilage is demarcated with a fissure, buckle, and/or wrinkle.			
Mobile Lesions	Locked door: Cartilage fissuring at periphery, unable to hinge open.			
	Trap door: Cartilage fissuring at periphery, able to hinge open.			
	Crater: Exposed subchondral bone defect.			

Figure 1. ROCK arthroscopy classification. ROCK, Research on Osteochondritis Dissecans of the Knee. (Reprinted with permission from Carey JL, Wall EJ, Grimm NL, et al. Novel arthroscopic classification of osteochondritis dissecans of the knee: a multicenter reliability study. *Am J Sports Med*. 2016;44(7):1694-1698.¹)

factors, or genetic predisposition.^{6,12} The presentation of OCD of the knee in young populations can vary widely from stable lesions that cause pain to unstable lesions that can present as a loose body with pain, swelling, and mechanical symptoms.¹⁰

Clinical presentation of OCD of the knee is varied; accordingly, treatment options vary greatly from nonoperative treatment with limitations on activity and weight-bearing to operative interventions. The decision for surgical intervention is generally based on a combination of clinical signs and symptoms along with radiographic and magnetic resonance imaging (MRI) findings to determine OCD characteristics. Operative intervention for OCD of the knee generally consists of knee arthroscopy to further assess the relative mobility or stability of the lesion. Traditionally, a multitude of classifications for knee OCD lesions at the time of surgery have been used,⁸ but more recently the Research on Osteochondritis

Dissecans of the Knee (ROCK) Group, an international group of OCD researchers and clinicians, developed a more objective and reliable arthroscopy classification for these lesions (Figure 1).¹ This classification, determined at the time of arthroscopy, includes 6 different lesion types grouped into 2 broader groups of mobile or immobile lesions. Mobile lesions include locked door, trap door, and crater lesions, and immobile lesions include cue ball, shadow, and wrinkle in the rug lesions.

Even though operative treatment options vary for different OCD lesion categories, the mobility of the lesion at the time of arthroscopy is relevant to determine appropriate surgical treatment. Operative treatment strategies include transarticular or retroarticular drilling of less mobile lesions, fixation of more mobile lesions, and salvage type reconstruction of lesions that have failed fixation or are not amenable to fixation. Preoperative knowledge of the mobility or stability of the knee OCD lesion is valuable

information for the surgeon, patient, and family. Preoperative prediction of lesion mobility at the time of arthroscopy could inform preoperative decision-making.

The current investigation aimed to develop a simple, clinical-based predictive model that could be used to differentiate lesion mobility before arthroscopic surgery. The hypothesis was that a multivariable model including patient demographic characteristics and physical examination findings at clinical presentation would differentiate the arthroscopically confirmed mobility status of the OCD lesion with high sensitivity and specificity.

METHODS

Patient data for the predictive modeling came from a multi-center national prospective cohort of patients with OCD lesions of the knee. The ROCK prospective cohort is a longitudinal prospective study including 23 institutions across North America (ClinicalTrials.gov, NCT02771496). The ROCK OCD longitudinal cohort follows prospectively enrolled patients with knee OCD lesions from presentation to long-term follow-up. This includes patients who are treated both nonoperatively and operatively for their knee OCD lesions. Patient data included in the prospective cohort include demographic data, physical examination data, and radiographic and MRI data. Although the data used in this model came from the prospective cohort, our hypotheses were investigated retrospectively. The entirety of variables collected are included in Appendix 1 (available in the online version of this article). However, only the clinical predictive variables were included in the final model. Inclusion criteria for the current subgroup analysis of the prospective cohort were patients ≥ 19 years of age, operatively treated OCD of the medial or lateral femoral condyle, and arthroscopically confirmed mobility status of the OCD lesion (Figure 2).

Demographic, preoperative physical examination, and radiographic data were summarized and compared by lesion type (Appendix 1, available online). These data were gathered from the surgeon baseline and imaging forms collected through the ROCK prospective cohort. Range of motion (ROM) and effusion were assessed by the surgeon at the time of presentation. Effusion was defined by the presence of an effusion compared with the contralateral knee, and ROM was defined as any loss of motion compared with the contralateral knee. Bivariate comparisons were conducted via univariable logistic regression models for the likelihood of mobile lesion. Multivariable logistic regression analysis using stepwise model selection was used to determine factors associated with the likelihood of a mobile versus an immobile lesion. Stepwise selection was based on model fit using the Akaike information criterion. Receiver operating characteristic (ROC) curve analyses were used to dichotomize relevant variables for a final predictive model using the Youden index. The Youden index identifies a cutoff value that simultaneously maximizes sensitivity and specificity. We reviewed the relevant variables included in the final model and all cutoff

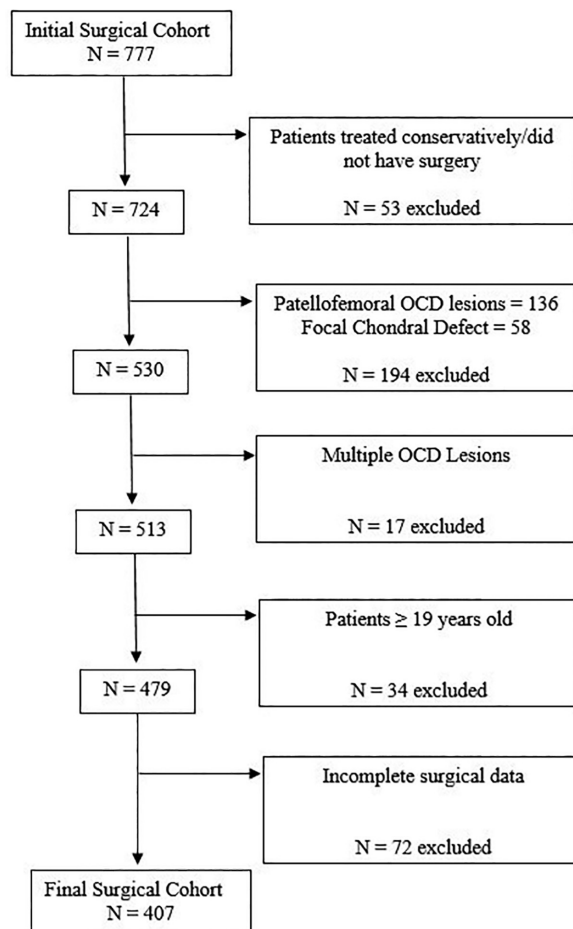


Figure 2. CONSORT flow diagram. OCD, osteochondritis dissecans.

values for clinical utility before model validation. A 75% partition of the data was used for model training, and 25% was held out for model validation testing. Quantitative model fit statistics were computed using the holdout data, including sensitivity, specificity, and the area under the ROC curve (AUC), along with the corresponding 95% CI. Missing demographic or clinical data were imputed using multivariate imputation by chain equations. No more than 20% of any given variable had missing data, and no deviations from variable distributions between raw and imputed data were detected. All tests were 2-sided, and $P \leq .05$ was considered significant.

RESULTS

Of the 407 patients who met inclusion criteria, 235 (58%) were found to have immobile lesions and 172 (42%) had mobile lesions, as defined using the ROCK classification at the time of arthroscopy by the treating surgeon.¹ Mean chronologic age of the 407 patients was 13.7 $\pm$ 2.2 years, and 62% of the patients were male. Mean height was 161.9 $\pm$ 5.3 cm and weight was 59.2 $\pm$ 42.2 kg.

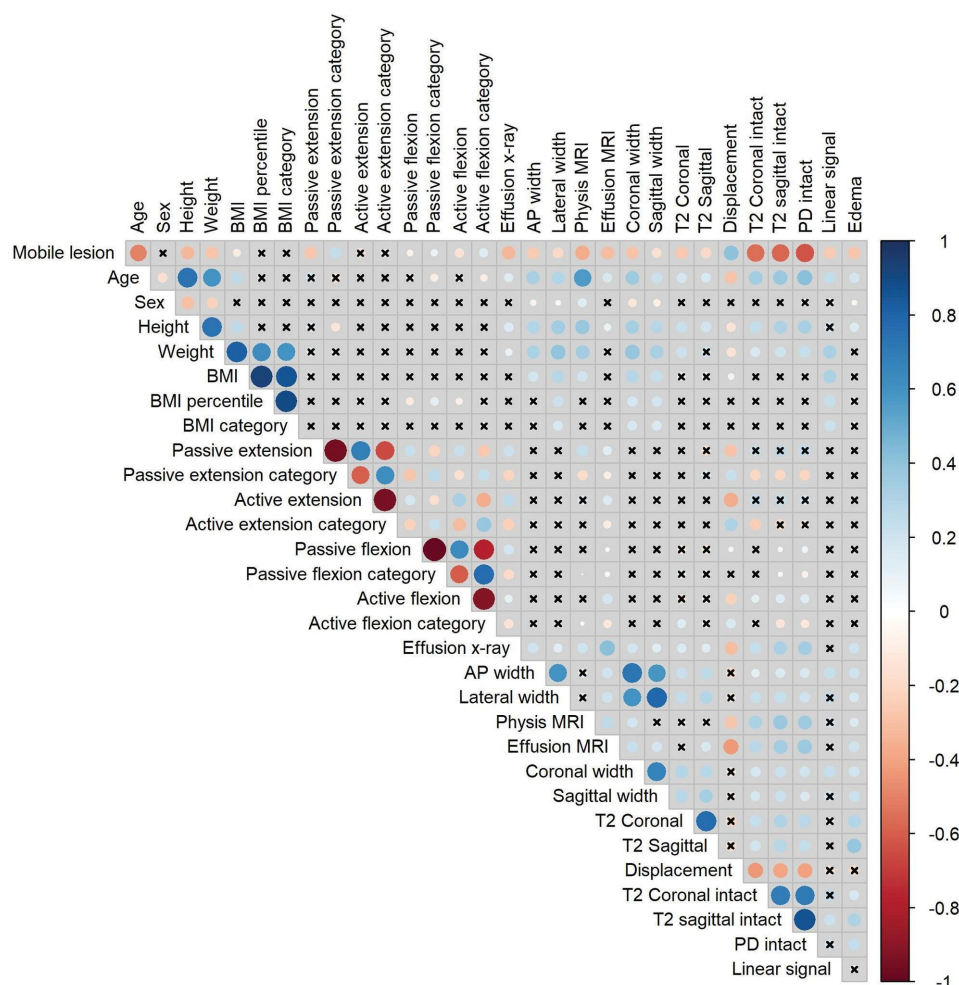


Figure 3. Correlation plot of demographic, clinical, and radiographic characteristics. The color and size of the circle indicate the magnitude and direction of the Spearman rank correlation coefficient. An X indicates no statistical significance of the correlation. BMI, body mass index.

Mean BMI was 22.0 $\pm$ 5.2. Patient characteristics are summarized in Table 1. Variables examined in the multivariable logistic regression are summarized in Figure 3. These variables were collected as part of the ROCK prospective cohort. Due to previous investigations which demonstrated that MRI assessments of OCD lesions have low interrater reliability, MRI characteristics were not included in this clinical model.⁷

We found that 21% of the total cohort had an effusion on physical examination and 23% had reduced ROM in either flexion or extension compared with their contralateral knee. Patient clinical data, in regard to effusion and ROM, are summarized in Table 2.

Using the training dataset, multivariable analysis determined that the best model to predict lesion type included chronologic age ≥ 14 years ($P < .001$), effusion on physical examination ($P < .001$), and any loss of ROM on physical examination ($P = .07$), while controlling for male sex ($P = .38$) and weight ≥ 54.4 kg ($P = .12$). In the 25% holdout validation sample ($n = 102$), an AUC of 0.89

(95% CI, 0.82-0.95) was achieved, indicating excellent discriminant ability of the algorithm to distinguish lesion type. Furthermore, the model produced a sensitivity of 83% and a specificity of 82% for validation prediction (Figure 4).

Predicted probabilities based on input factors are listed in Table 3. For example, a patient ≥ 14 years of age at surgery, with some loss of ROM, and with effusion on clinical examination had between 85% and 92% probability of having a mobile lesion (increasing for patients ≥ 54.4 kg and/or male). Conversely, a patient < 14 years at surgery of age, with no loss of ROM, and no effusion on clinical examination had between 8% and 16% probability of having a mobile lesion.

DISCUSSION

The partition of data used for model training (75%), taken from easily obtainable clinical data at presentation, yielded

TABLE 1
Patient Characteristics by Lesion Type (N = 407)^a

Characteristics	Mobile Lesions (n = 172)	Immobile Lesions (n = 235)	P
Age at surgery, y	15.1 6 2.1	12.8 6 1.7	\.001
Age 2:14 y at surgery	131 (76)	48 (20)	\.001
Male sex	109 (63)	145 (62)	.81
White race	124 (72)	174 (74)	.37
Height, cm	167.4 6 4.9	157.7 6 5.0	\.001
Weight, kg	67.1 6 44.4	53.5 6 35.6	\.001
Weight .54.4 kg	129 (75)	95 (40)	\.001
BMI	23.5 6 5.7	21.1 6 4.6	\.001
BMI percentile, median (IQR)	74 (46-93)	74 (48-91)	.73
Category			.26
Underweight	4 (2)	7 (3)	
Healthy weight	111 (65)	147 (63)	
Overweight	20 (12)	42 (18)	
Obese	37 (22)	39 (17)	

^aValues are expressed as mean 6 SD or n (%) unless otherwise noted. BMI, body mass index.

TABLE 2
Loss in Range of Motion Clinical
by Lesion Type (N = 407)^a

Characteristic	No	Yes	P
Loss in range of motion .0°			
Passive extension	36 (21)	12 (5)	\.001
Active extension	31 (18)	10 (4)	\.001
Passive flexion	49 (29)	21 (9)	\.001
Active flexion	58 (34)	28 (12)	\.001

Characteristic	(n = 172)	(n = 235)	P
Any effusion of the involved knee	66 (38)	24 (10)	\.001
Loss in range of motion .0°			\.001
Passive extension	36 (21)	12 (5)	\.001
Active extension	31 (18)	10 (4)	\.001
Passive flexion	49 (29)	21 (9)	\.001
Active flexion	58 (34)	28 (12)	\.001

TABLE 3
Clinical Predictive Model^a

Age 2:14 y	.0° of ROM Loss	Effusion on Examination	Weight .54.4 kg	Male Sex	Predicted Probability of Mobile Lesion, %
Yes	Yes	Yes	Yes	Yes	92
				No	90
			No	Yes	88
				No	85
		No	Yes	Yes	86
				No	83
				Yes	79
No	Yes	Yes	Yes	Yes	75
				No	70
		No	Yes	Yes	64
				No	58
				No	74
	No	Yes	Yes	60	
			No	54	
		No	Yes	48	
			No	41	

Any loss of range of motion 63 (37) 29 (12) \.001

^aData are expressed as n (%).

a highly sensitive and specific predictive model for differentiation of mobile versus immobile OCD lesions of the knee in pediatric and adolescent patients. Specifically, this clinical model indicates that a patient presenting with chronologic age of 2:14 years, evidence of a knee effusion on physical examination at the time of initial presentation, and reduced ROM relative to the contralateral knee has between an 85% and 92% likelihood of a mobile lesion compared with an immobile lesion using the ROCK arthroscopy classification at the time of surgery. This is the first predictive model to predict relative instability of an OCD lesion at the time of arthroscopic evaluation using only preoperative clinical data.

OCD, a focal idiopathic alteration of subchondral bone with a

risk for instability and disruption of adjacent articular cartilage that may result in premature osteoarthritis⁵ continues to be challenging pathology for patients, families, and treating clinicians alike. The American Academy of Orthopaedic Surgeons developed a clinical practice

No	Yes	Yes	16
		No	13
	No	Yes	10
		No	8

^aROM, range of motion.

guideline (CPG) for the diagnosis and treatment of OCD in 2011.² Although most of the recommendations were largely weak or inclusive, this CPG has guided the research efforts of the ROCK Group as well as others over the last decade.

In response to the lack of consensus on most of the CPG, consideration was first given to being able to provide a common language or set of classifications in the diagnosis of OCD of the knee. Traditionally, a multitude of classifications for knee OCD lesions at the time of surgery have been used,⁸ but more recently the ROCK Group, an international group of OCD researchers and clinicians, has developed a more reliable and valid arthroscopy classification for these lesions.¹ This classification determined at the time of arthroscopy includes 6 different lesion types

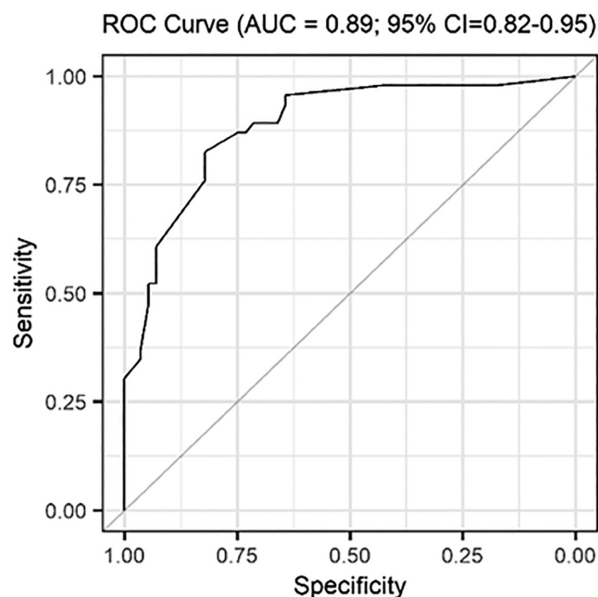


Figure 4. Receiver operating characteristic (ROC) curve of model using validation sample. AUC, area under the ROC curve.

divided into 2 broader groups of mobile or immobile lesions. This provided excellent intrarater and interrater reliability.

Additional studies examining radiographic and MRI classifications of knee OCD lesions have shown mixed results. Parikh et al¹¹ showed insufficient interrater reliability of “healing” on radiographic evaluations. Wall et al¹⁴ showed excellent interrater reliability of OCD overall healing as well as 5 subfeatures of OCD healing, including boundary, sclerosis, size, shape, and ossification. In regard to MRI assessment of OCD lesions, reliability was examined by Fabricant et al.⁷ Those authors found acceptable reliability for a few MRI characteristics and measurements, but most of the other MRI characteristics were found to have unacceptable reliability.

The ability to predict the mobility of knee OCD lesions before surgical intervention can facilitate improved surgical planning and more relevant communication with families regarding the procedures that will be required. Specifically, preoperative determination of lesion mobility can aid in distinguishing between less invasive interventions such as drilling versus more invasive procedures such as OCD fixation and salvage. In some cases it may be quite obvious that a lesion is displaced: For example, a displaced osteochondral fragment is seen on plain radiographs. In other cases, it might not be obvious whether an OCD lesion of the knee is a mobile or an immobile lesion. A key aspect of this predictive model is that it uses basic clinical data that are obtained at patient presentation and on examination, including age, sex, weight, presence of effusion, and knee ROM.

Wall et al¹⁴ previously examined predictive factors, primarily focused on MRI-derived metrics, for OCD healing and developed a nomogram that predicted healing status

for nonoperatively treated OCD lesions. The previous report indicated that young patient age, smaller normalized size of the lesion, and lack of mechanical symptoms were predictive of healing of OCD lesions with nonoperative treatment.¹⁴ The study presented here is the first study to use preoperative characteristics to predict intraoperative findings.

Strengths of the current study include that it represents the largest study of OCD lesions of the knee in young patients.¹⁰ Because the prospective cohort database includes demographic, anthropomorphic, physical examination, and radiologic data, we had access to a wide range of potential markers and factors that may affect the mobility of the lesion. Having a large and highly generalizable patient pool providing knee OCD lesions allowed for robust statistical modeling with a 75%/25% partition, including a training dataset used for model development and 25% of the patient population held for model validation. The current model is both simple in data acquisition and parsimonious in that it uses variables that are easy to measure and understand (age, presence of effusion palpable on examination, and ROM) and does not require expensive imaging studies such as MRI or the interpretation of MRI scans. The challenges associated with interpreting MRI scans of knee OCD lesions has been previously reported.⁷ MRI and radiography are still crucial components of the diagnostic workup for knee OCD lesions. The clinical predictive model developed here helps identify lesion mobility, but imaging is still crucial in knee OCD diagnostics.

There are limitations to this study and the resulting model. We excluded patellofemoral lesions because the radiologic parameters are difficult to compare with the same imaging parameters and measurements used for femoral condylar lesions. Consequently, this information may not apply to patellofemoral OCD lesions, as it is possible that patellofemoral OCD lesions would have different risk factors for mobility. Further study of patellofemoral OCD lesions is warranted. Although this study can help predict the mobility of the lesion using the ROCK arthroscopy classification, it does not indicate which procedures are most appropriate or likely to lead to successful healing of these OCD lesions. Further study and longer term follow-up are needed to investigate healing potential based on the ROCK arthroscopy classification and related treatment strategies. Other limitations include the fact that the current model predicts only mobile lesions versus immobile lesions and does not predict the individual 6 types of ROCK arthroscopy classification type lesions. Although the current model is fairly simple to use and entails demographic and physical examination findings, it does not incorporate advanced imaging such as MRI. Although radiographic and MRI data were examined, these data did not enhance the clinical predictive ability of our model. Although the study used a 25% holdout sample and the cohort involves multiple centers, there may be inherent issues with modeling on the single cohort. Ideally, the model should be applied to cases prospectively moving forward or tested on other patient populations or cohorts. Also, it is important to note that sex and weight were

included because they are important factors that have been shown to increase risk for OCD in some populations, but they were not as strong as the other 3 variables.

CONCLUSION

A predictive model using chronologic age, sex, weight, presence of effusion, and lack of full ROM at time of presentation was predictive of mobility of knee OCD lesions at the time of arthroscopy using the ROCK arthroscopy classification. Preoperative knowledge of the mobility or stability of the knee OCD lesion would be valuable information for the surgeon, patient, and family. Preoperative prediction and understanding of the mobility of the lesion at the time of arthroscopy could improve preoperative decision-making.

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