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Association of Meniscal Status, Lower Extremity Alignment, and Body Mass Index With Chondrosis at Revision Anterior Cruciate Ligament Reconstruction

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Background: Knees undergoing revision anterior cruciate ligament reconstruction (rACLR) have a high prevalence of articular cartilage lesions.

Hypothesis: The prevalence of chondrosis at the time of rACLR is associated with meniscal status and lower extremity alignment.

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

Methods: Data from the prospective Multicenter ACL Revision Study (MARS) cohort were reviewed to identify patients with preoperative lower extremity alignment films. Lower extremity alignment was defined by the weightbearing line (WBL) as a percentage of the tibial plateau width, while the chondral and meniscal status of each weightbearing compartment was recorded at the time of surgery. Multivariable proportional odds models were constructed and adjusted for relevant factors to examine which risk factors were independently associated with the degree of medial and lateral compartment chondrosis.

Results: The cohort included 246 patients with lower extremity alignment films at the time of rACLR. Mean (±SD) patient age was 26.9 ± 9.5 years and body mass index (BMI) was 26.4 ± 4.6. The medial compartment had more chondrosis (grade 2/3, 42%; grade 4, 6.5%) than did the lateral compartment (grade 2/3, 26%; grade 4, 6.5%). Disruption of the meniscus was noted in 35% of patients on the medial side and 16% in the lateral side. The mean WBL was 0.43 ± 0.13. Medial compartment chondrosis was associated with BMI ($P = .025$), alignment ($P = .002$), and medial meniscal status ($P = .001$). None of the knees with the WBL lateral to 0.625 had grade 4 chondrosis in the medial compartment. Lateral compartment chondrosis was significantly associated with age ($P = .013$) and lateral meniscal status ($P < .001$). Subjects with ''intact'' menisci were found to decrease their odds of having chondrosis by 64% to 84%.

Conclusion: The status of articular cartilage in the tibiofemoral compartments at the time of rACLR is related to meniscal status. Lower extremity alignment and BMI are associated with medial compartment chondrosis.

Keywords: meniscus; meniscectomy; varus; valgus; osteoarthritis; ACL reconstruction

Outcomes are known to be less favorable in revision anterior cruciate ligament reconstructions (rACLR) than after primary anterior cruciate ligament (ACL) reconstructions.[21,27,43,46,47] These outcomes are likely to be influenced by the status of the menisci and articular cartilage.[2] Knees undergoing rACLRs have more intra-articular injuries than knees undergoing primary reconstruction,[12,20] as 90% of knees undergoing rACLR have been found to have meniscal or chondral injury while 57% had both at the time of rACLR.[29] Meniscal injury[26,39,48] and the amount of meniscus removed at ACL reconstruction[17] have been shown to be associated with the subsequent development of arthrosis. In a previous study of the Multicenter ACL Revision Study (MARS) cohort, partial meniscectomies occurring before rACLR were shown to be associated with a higher rate of chondrosis at the time of rACLR compared with previous meniscal repair or no previous meniscal surgery.[6] There was no difference in the prevalence of chondrosis in the knee between patients who had a previous meniscal repair and patients who had no previous meniscal surgery.

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However, the status of the meniscus at the time of rACLR was not assessed in that study.

Another variable likely to influence the incidence of chondrosis is lower extremity alignment, specifically the location of the weightbearing axis in the knee. Varus malalignment has been shown to predict the development of medial compartment osteoarthritis.[1,8,42] The integrity of the menisci and the alignment of the lower extremity are likely to influence the prevalence of chondrosis in the tibiofemoral compartments of the knee at the time of rACLR. Since obesity has been shown to be associated with a greater risk of meniscal tears, partial meniscectomy,[11,15,18] and osteoarthritis in the knee,[4,7,16] body mass index (BMI) is another variable that may be important in this population.

The current study was designed to advance our understanding of factors influencing the prevalence of chondrosis in the tibiofemoral compartments of the knee at the time of rACLR. The purpose of this study was to test the following hypotheses: (1) meniscal loss is associated with the prevalence of chondral lesions in the same compartment of the knee at the time of rACLR, and (2) lower extremity alignment is associated with the prevalence of chondral lesions in the tibiofemoral compartments at the time of rACLR.

METHODS

Setting and Study Population

The patients in this study were enrolled in the MARS Study, an academic and private practice multicenter consortium (83 surgeons in 52 sites), funded by the National Institutes of Health and sponsored by AOSSM, that is conducting an ongoing prospective cohort study of patients undergoing rACLR.[29] All participating sites obtained local institutional review board approval before enrolling subjects and complied with a standardized manual of operations. Participating surgeons were required to complete a training session that integrated intra-articular agreement studies, review of the study design, and inclusion criteria. They also completed a practice intra-articular grading sheet and a trial surgeon questionnaire.

The recruitment period for the current study was between 2006 and 2011. Subject inclusion criteria incorporated any patients undergoing revision of a previously failed ACL reconstruction who agreed to participate, signed an informed consent, and completed a series of patient-reported validated outcome instruments. Indications for rACLR included functional instability, abnormal laxity testing, or a magnetic resonance imaging (MRI) result that indicated graft tear.

Data Sources and Measurement

Patients with bilateral weightbearing, long-leg alignment films taken just before their revision surgery were eligible to be included in this study. While these films had been recommended for all patients enrolled in the MARS study, they were not required and were only collected if surgeons used them as standard of care. Lower extremity alignment films were available for 246 of 1200 patients (20.5%). There was little variability in the indications for obtaining films, as participating surgeons typically either obtained these films on nearly all of their patients (as standard of care) or on almost none.

Limb alignment was measured on a bilateral long-leg standing radiograph.[28] It was recommended that all centers use a similar technique with full extension, long-leg standing films in neutral rotation. The line from the center of the femoral head to the center of the ankle tibial plafond was drawn. The point where it intersected the tibial plateau was noted. The distance from this point to the medial border of the tibial plateau divided by the total width of the tibial plateau was expressed as a percentage for both extremities.

At the time of each surgery, surgeons documented all meniscal and chondral injuries and treatment using a standardized form. The chondral status of each weightbearing compartment was described as normal (none/grade 1 chondrosis), intermediate (grades 2/3 chondrosis on at least 1 surface), or advanced (grade 4 on at least 1 surface), using the modified Outerbridge classification system.[30,33] Each meniscus was described as intact or disrupted (torn or previously debrided) at the time of rACLR. Previous studies have demonstrated the ability of fellowship-trained sports surgeons to have agreement on meniscal[14] and chondral lesions.[30]

Quantitative Variables and Statistical Methods

The purpose of the study was to determine the association between chondrosis and meniscal status and lower extremity alignment at the time of rACLR. To that end, medial compartment chondrosis and lateral compartment chondrosis were the 2 dependent outcome variables, and the associations of factors at the time of rACLR were examined by use of proportional odds ordinal logistic models. Independent covariates controlled for in the model included age at the time of surgery, sex, BMI, activity level, revision number, previous graft type, lower extremity alignment, and compartmental meniscal status (Table 1). Parameter estimates were exponentiated to obtain odds ratios along with their corresponding 95% confidence intervals. All continuous covariates were modeled using a 3-knot restricted cubic spline to allow for a nonlinear relationship with the outcomes measures. To avoid casewise deletion of records with missing covariates, we used multiple imputations via prediction mean matching. *P* values are reported for each statistical contrast, using either the Kruskal-Wallis test (for continuous variables) or the Pearson test (for categorical variables). Statistical analysis was performed with the free open source R statistical software using the Hmisc and rms packages (http://www.r-project.org).[25]

RESULTS

Study Population

The cohort included all patients with lower extremity alignment films at the time of rACLR (246 patients).

TABLE 1
List of Modeling Variables

Category	Variable	Degrees of Freedom (df)	Levels
Patient demographics	Age in years	1	Continuous
	Sex	1	Male, female
	Body mass index	1	Continuous
	Baseline Marx activity level	1	Continuous
Surgical information	Revision number	1	1, ≥2
	Prior graft type	3	Autograft (bone–patellar tendon–bone), autograft (soft tissue), allograft, other/unknown
	Alignment	1	Continuous
	Meniscal pathology		
	Medial	1	Intact, disrupted
	Lateral	1	Intact, disrupted
	Articular cartilage pathology	2	Grades 0/1 (normal), grades 2/3 (intermediate), grade 4 (advanced) on at least 1 surface

Mean ± SD patient age was 26.9 ± 9.5 years, and mean ± SD BMI was 26.4 ± 4.6 (Table 2). There were 143 male patients (58%), and 213 (87%) were first-time revisions. The medial compartment had more chondrosis (intermediate 42%, advanced 6.5%) than the lateral compartment (intermediate 26%, advanced 6.5%). Disruption of the meniscus was noted in 35% of patients on the medial side and 16% in the lateral side. The mean ± SD weightbearing alignment axis was 0.43 ± 0.13, compared with 0.41 ± 0.13 in the contralateral limbs.[28]

Medial Compartment Chondrosis

Medial compartment chondrosis was associated with BMI (odds ratio [OR], 1.08; 95% CI, 1.01-1.15; $P = .025$), alignment (OR, 0.03; 95% CI, 0.0-0.3; $P = .002$), and medial meniscal status (OR, 0.36; 95% CI, 0.20-0.66; $P = .001$) (Table 3). The risk of medial compartment chondrosis at the time of rACLR increased by 8% with each unit of BMI. An intact medial meniscus decreased the risk of medial compartment chondrosis by 64%. For every 10% shift in the weightbearing line (WBL) lateral on the tibial plateau, the risk of medial compartment chondrosis decreased by 9.7%. None of the knees with the WBL lateral to 0.625 had grade 4 chondrosis in the medial compartment (Figure 1).

Lateral Compartment Chondrosis

Lateral compartment chondrosis was significantly associated with age (OR, 1.04; 95% CI, 1.01-1.08; $P = .013$) and lateral meniscal status (OR, 0.16; 95% CI, 0.08-0.32; $P < .001$) (Table 4). The risk of lateral compartment chondrosis increased by 4% with each year of aging, while an intact lateral meniscus decreased the risk of lateral compartment chondrosis by 84%. BMI and alignment were not associated with chondrosis in the lateral compartment.

Patient age, sex, activity level, revision number, and previous ACL graft type were not associated with chondrosis.

DISCUSSION

Chondrosis in the tibiofemoral compartments at the time of rACLR relates to the status of the meniscus in that compartment. Alignment and BMI are significantly associated with articular cartilage status in the medial compartment but not in the lateral compartment. Activity level, number of revisions, and previous ACL graft type were not associated with cartilage changes in the tibiofemoral compartments at the time of rACLR.

In a prior study from this cohort, the status of the articular cartilage at the time of rACLR was shown to relate to previous meniscal surgery.[6] Patients with previous partial meniscectomy had higher rates of chondrosis than patients with previous meniscal repair or no previous meniscal surgery. However, that study did not look at the status of the meniscus at the time of rACLR. The current study confirms that an intact meniscus at the time of rACLR reduces the risk of articular cartilage damage, which is not surprising given that meniscal tears are associated with chondrosis and osteoarthritis in the knee.[5,23,31,36,38] While one previous study reported 6 times more arthrosis in knees with concomitant partial meniscectomy at the time of ACL reconstruction,[26] another study did not find any association between the development of arthrosis and meniscal injury at the time of ACL reconstruction.[12]

More varus alignment increased the incidence of chondral damage in the medial compartment, but alignment was not associated with the rate of chondrosis in the lateral compartment. High tibial osteotomies are commonly accepted as an effective treatment for painful arthritis in the varus knee.[19] A recent biomechanical study showed that correction to between 6° and 10° of anatomic valgus completely unloads the medial compartment.[32] While many would agree that transferring the weightbearing axis to 62.5% of the tibial width (from medial to lateral) is the target for high tibial osteotomy in the varus knee,[19] limited data are available on the dose response to, and optimal target for, correction of alignment. Our data demonstrate that the medial compartment is at risk

TABLE 2
Baseline Demographic and Clinical Characteristics at the Time of rACLR[a]

Characteristic	
Age, y	19, 25, 33
Sex	
Male	58 (143)
Female	42 (103)
Body mass index	22.7, 25.2, 28.7
Baseline Marx activity level	4, 11, 16
Revision number	
1	87 (213)
≥2	13 (33)
Previous graft type	
Autograft (BTB)	38 (93)
Autograft (soft tissue)	32 (78)
Allograft	26 (65)
Other/unknown	4 (10)
Alignment	0.35, 0.43, 0.50
Medial meniscal status	
Intact	65 (161)
Disrupted	35 (85)
Lateral meniscal status	
Intact	84 (207)
Disrupted	16 (39)
Medial compartment chondrosis	
Grades 0/1 (normal)	51 (126)
Grades 2/3 (intermediate)	42 (104)
Grade 4 (advanced)	7 (16)
Lateral compartment chondrosis	
Grades 0/1 (normal)	67 (166)
Grades 2/3 (intermediate)	26 (64)
Grade 4 (advanced)	7 (16)
Previous high tibial osteotomy	
No	98 (242)
Yes	2 (4)
Previous medial meniscal transplant	
No	100 (245)
Yes	0 (1)
Previous lateral meniscal transplant	
No	100 (246)
Yes	0 (0)

[a]Values are expressed as % (n) or as *a, b, c*, where *a* represents the lower quartile, *b* the median, and *c* the upper quartile for continuous variables. BTB, bone–patellar tendon–bone; rACLR, revision anterior cruciate ligament reconstruction.

for chondral damage in varus knees that have undergone ACL reconstruction but that knees with more valgus alignment are less likely to have chondrosis in the medial compartment. This association suggests that a high tibial osteotomy is an intervention with potential for chondroprotection in these patients, particularly when the weightbearing axis is medial to 50% of the tibial width, and possibly when the weightbearing axis is medial to 62.5% of the tibial width. However, the current study did not evaluate the effect of realignment surgery, and more research is necessary to assess this possible relationship. Our findings are consistent with a recent study reporting that many rACLR patients are good candidates for high tibial osteotomy.[45]

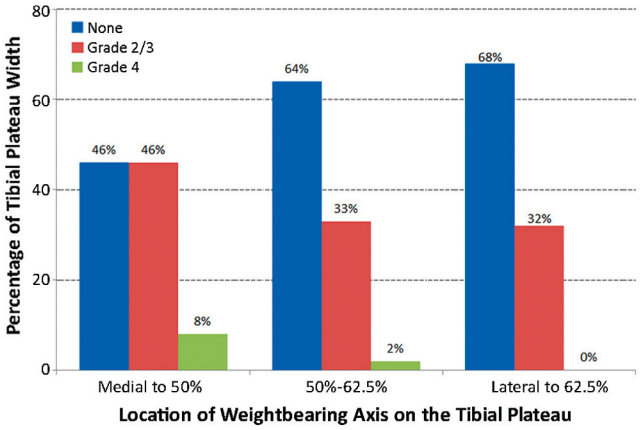

Figure 1. Distribution of chondrosis in medial compartment by lower extremity alignment.

Elevated BMI is a potentially modifiable, and even preventable, risk factor for knee osteoarthritis.[9,16,37] Obesity is likely to have both biomechanical and biochemical links to osteoarthritis.[35,44] A recent study demonstrated that obesity modulated changes in the gene expression of meniscal tears, which may be particularly pertinent in rACLR patients with meniscal tears.[34] The elevated risk for medial compartment chondrosis at the time of rACLR with higher BMI may partly explain why BMI at the time of ACL reconstruction has been shown to predict lower activity level at 2 and 6 years after surgery.[13,40] Patients who have undergone ACLR, and especially those undergoing rACLR, should be counseled on the potential benefits to their knee cartilage from maintaining a normal BMI.

Meniscal and articular cartilage damage is associated with worse outcomes after ACL reconstruction,[24,39,48] and the presence of chondral injury at the time of rACLR has been associated with worse outcomes in these patients.[3,10,22,41] Considering the increased incidence of medial compartment chondrosis at the time of rACLR in patients with varus malalignment and deficient medial meniscus, knees in varus malalignment undergoing partial meniscectomy at the time of ACL reconstruction have the potential to benefit from a high tibial osteotomy to reduce the risk of developing chondrosis. The exact alignment at which such a procedure should be considered, medial to 50% or 62.5% of the tibial width, is not clear from our data. Again, much more research is needed before such intervention could be recommended.

Lateral compartment chondrosis was not associated with BMI and alignment, whereas medial compartment chondrosis was associated with these variables. The differential association of alignment may be at least partly explained by the preponderance of varus alignment in this population. However, the lack of association with BMI in the lateral compartment is less easily explained. Perhaps, if the influence of BMI on chondrosis is magnified by meniscal deficiency, the greater prevalence of medial meniscal tears (35% vs 16%) is important.

It is also not clear why the medial compartment had a higher prevalence of meniscal tears and chondrosis in this population. The role of the medial meniscus as

TABLE 3
Medial Compartment Chondrosis: Logistic Model Results[a]

Variable	Odds Ratio	95% CI	*P* Value
Age	1.02	0.99-1.06	.149
Sex (male vs female)	0.70	0.39-1.26	.234
Body mass index	1.08	1.01-1.15	**.025**
Baseline Marx activity level	0.97	0.92-1.02	.198
Revision number (≥2 vs 1)	0.72	0.30-1.73	.464
Previous graft type			
Autograft (BTB) vs allograft	0.83	0.41-1.70	.613
Autograft (soft tissue) vs allograft	0.88	0.43-1.80	.720
Other/unknown vs allograft	1.21	0.29-5.05	.793
Alignment	0.03	0.00-0.30	**.002**
Medial meniscal status (intact vs disrupted)	0.36	0.20-0.66	**.001**

[a]Bolded values indicate statistical significance ($P < .05$). BTB, bone–patellar tendon–bone.

TABLE 4
Lateral Compartment Chondrosis: Logistic Model Results[a]

Variable	Odds Ratio	95% CI	*P* Value
Age	1.04	1.01-1.08	**.013**
Sex (male vs female)	0.79	0.42-1.50	.475
Body mass index	1.02	0.96-1.09	.500
Baseline Marx activity level	1.04	0.99-1.10	.137
Revision number (≥2 vs 1)	1.20	0.49-2.99	.688
Previous graft type			
Autograft (BTB) vs allograft	0.93	0.43-2.00	.855
Autograft (soft tissue) vs allograft	1.54	0.72-3.29	.264
Other/unknown vs allograft	1.38	0.31-6.04	.671
Alignment	0.80	0.08-7.78	.845
Lateral meniscal status (intact vs disrupted)	0.16	0.08-0.32	**<.001**

[a]Bolded values indicate statistical significance ($P < .05$). BTB, bone–patellar tendon–bone.

a secondary stabilizer of the knee may be relevant, especially in these knees that have experienced at least 2 episodes of ACL deficiency (after the tear of the native ACL and at least 1 tear of a reconstructed ACL). As mentioned above, the bias toward varus alignment, and the association of alignment and BMI with medial compartment chondrosis but not lateral compartment chondrosis, may contribute to this discrepancy.

Limitations of the present study include the potential interobserver variance in reported chondrosis and meniscal status data and the fact that we did not quantify the extent of the meniscal or cartilage loss. A number of potential confounding variables, including previous articular cartilage injury, the status of the articular cartilage injury at the time of previous knee surgery, and the presence/absence of subchondral bone bruise at the time of initial/secondary ACL injury, were not consistently available for this cohort and were therefore not analyzed. Association does not necessarily imply causation; for example, it is possible that chondrosis leads to meniscal tears rather than the converse relationship. No data were available on time intervals between initial knee injury and primary ACLR, previous knee surgery and current rACLR, or the most recent graft failure and current rACLR, all of which could affect findings. The association between cartilage loss and varus alignment does not support conclusions about causation. While varus malalignment may predispose to cartilage loss in the medial compartment, it is also likely that cartilage loss or meniscal deficiency in the medial compartment, or both, contribute to varus malalignment. We cannot differentiate between patients with such a secondary varus malalignment and those with a primary varus malalignment. Furthermore, it is possible that a selection bias exists with regard to which patients had alignment films, although they were collected as standard of care based on surgeon practice. Finally, this study includes patients who have undergone surgery by a wide variety of surgeons, which may be a limitation, or a strength, in terms of the generalizability of the findings.

Despite these limitations, this is a large prospective study correlating meniscal status and alignment with intra-articular findings. An intact meniscus is associated with less articular cartilage damage in the associated tibiofemoral compartment at the time of rACLR. More varus alignment and elevated BMI are associated with worse chondrosis in the medial compartment. These findings emphasize the importance of the meniscus and the relevance of alignment and BMI to the articular cartilage in these patients. Further research is needed to understand the potential of surgical

interventions (ie, meniscal repair or replacement, realignment osteotomy), as well as weight maintenance and/or loss, to reduce or delay this cartilage damage.

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