Knee Cartilage Defect Characteristics Vary among Symptomatic Recreational and Competitive Scholastic Athletes Eligible for Cartilage Restoration Surgery

Joshua S. Everhart¹, Zak Boggs¹, Alex C. DiBartola¹, Brennan Wright¹, and David C. Flanigan¹

Abstract

Objective. To determine whether there are differences by sport or competitive level in symptomatic knee cartilage defects among recreational, high school, or collegiate competitive athletes undergoing initial arthroscopic knee surgery who meet criteria for cartilage restoration surgery. **Design.** Three hundred recreational ($n = 172$) and high school or collegiate competitive athletes ($n = 128$) younger than 40 years and body mass index (BMI) $<35 \text{ kg/m}^2$ (63% male, mean age 24.3 years, SD 7.1; mean BMI 25.7 kg/m^2 , SD 3.7) with Outerbridge grade 2 or higher symptomatic cartilage defects who underwent arthroscopic knee surgery were identified. The independent relationship between sporting activity or competitive level and cartilage defect location, size, severity, and symptom chronicity were assessed by multivariate regression analysis. **Results.** Full-thickness defects were present in 24% of competitive athletes and 31% of recreational athletes ($P = 0.21$). There was a trend toward an independent association with competitive level and high-grade (3 or 4) multicompartiment disease (adjusted odds ratio [aOR] 3.99, 95% confidence interval 0.84–18.8; $P = 0.08$) or isolated anterior compartment defects (aOR 2.00, 95% CI 0.86–4.62, $P = 0.10$) but not isolated medial or lateral defects. High-grade defect size was similar among recreational and competitive athletes ($P = 0.71$). High-grade lateral defect prevalence differed by sport (running 24%, basketball 23%, soccer 18%, football 5%; $P = 0.02$) but not medial or anterior defect prevalence. **Conclusions.** Among recreational and high school or collegiate competitive athletes with symptomatic cartilage defects who meet criteria for cartilage restoration, competitive athletes may have higher risk of high-grade anterior and multicompartiment defects but no difference in defect size.

Keywords

knee cartilage defects, cartilage defects in athletes, sport-specific injury patterns

Introduction

Articular cartilage injuries of the knee are encountered quite commonly by orthopedic surgeons, with approximately 200,000 to 300,000 cartilage defect procedures being performed annually in the United States.¹ Patients presenting with symptomatic defects will typically display longstanding activity-related swelling accompanied by knee pain, which can be highly debilitating,² and in younger patients, full-thickness defects have been shown to produce a quality of life similar to those with severe knee osteoarthritis awaiting arthroplasty.³ Given the limited regenerative capacity of cartilage because of its avascular nature, cartilage injury may lead to early-onset arthritis,^{4,5} potentially necessitating early total knee arthroplasty. Existing cartilage damage is associated with accelerated local cartilage damage^{6–11} and increases risk of subsequent cartilage damage in other regions of the knee.¹²

Focal knee cartilage defects have a high prevalence in athletic populations. A systematic review from Flanigan *et al.*¹³ found a 36% prevalence of full-thickness focal cartilage defects in athletes, with 14% being asymptomatic at time of diagnosis. The functional demands on the knee joint vary significantly by sporting activity,¹⁴ and sport-specific patterns of cartilage lesions have been identified.^{13,15} Full-thickness cartilage defects are 47.5% more common in professional basketball players than the general asymptomatic population¹⁶; professional basketball athletes display more

¹Department of Orthopaedics, The Ohio State University Wexner Medical Center, Columbus, OH, USA

Corresponding Author:

David C. Flanigan, Sports Medicine Research Institute, The Ohio State University Wexner Medical Center, 2835 Fred Taylor Drive, Columbus, OH 43202, USA.

Email: david.flanigan@osumc.edu

Table 1. Study Inclusion Criteria.

Inclusion criteria
Age less than 40 years and body mass index 35 kg/m ² or less
Patient underwent knee arthroscopic surgery between 2007 and 2013
Concomitant ligament and/or meniscus injuries permitted
Symptomatic Outerbridge grade 2 or higher focal cartilage defect visualized on diagnostic arthroscopy
Kellgren-Lawrence grade 2 or less and less than 50% joint space narrowing on weightbearing flexion posterior-anterior knee radiographs
Recreational and scholastic competitive athletes permitted. Recreational athlete status was defined as habitual performance of a sporting activity at least 3 times per week either independently or in a recreational sporting league. Scholastic competitive athlete status was defined as performance of a sporting activity in a school-sponsored sport with regular participation in competitive sporting events

Table 2. Outerbridge Classification for Cartilage Defects.

Grade	Definition
Grade 0	Normal
Grade 1	Cartilage with softening and swelling
Grade 2	A partial-thickness defect with fissures on the surface that do not reach subchondral bone, or exceed 1.5 cm in diameter
Grade 3	Fissuring to the level of subchondral bone in an area with a diameter more than 1.5 cm
Grade 4	Exposed subchondral bone

patellofemoral and trochlear defects than femoral condyle defects,^{13,15} which are hypothesized to be secondary to strong extensor mechanism contractions during plyometric jumping. In contrast, professional soccer players display more femoral condyle defects compared with patellofemoral and trochlear lesions (78% to 18%).¹⁵

Though defect prevalence among athletes is well studied, it is unclear whether arthroscopically assessed knee cartilage defect characteristics differ by sport or competitive level among symptomatic athletes who meet demographic (age <40 years and body mass index [BMI] <35 kg/m²) and radiographic (<50% joint space narrowing on weight bearing radiographs criteria for cartilage restoration surgery. High-level athletes have been reported to have better return to sport rates than lower competition level athletes following cartilage restoration,^{17,18} and return to high impact or rapid stop-start sports following cartilage restoration tends to have lower success rates with a higher likelihood of transition to endurance and lower intensity exercises.¹⁹ However, cartilage restoration outcome studies in athletes frequently do not differentiate lesion characteristics or outcomes by sport or competitive level,²⁰⁻²² and many studies are focused on professional-level athletes^{20,23} rather than athletes at the high school or collegiate competitive level.²⁴ Therefore, the purpose of the current study was to determine whether there are differences by sport or competitive level in symptomatic knee cartilage defect location, chronicity, size, or grade among recreational or high school or collegiate competitive athletes undergoing initial arthroscopic

knee surgery who meet demographic and radiographic criteria for cartilage restoration surgery.

Methods

Following institutional review board approval, consecutive cases of athletes ($n = 476$) who underwent initial arthroscopic knee surgery at a single institution between 2007 and 2013 were reviewed for the present study inclusion criteria (**Table 1**). All patients had at least 1 focal Outerbridge²⁵ grade 2 or higher cartilage defect (**Table 2**); patients with existing osteoarthritis (defined as Kellgren-Lawrence grade 3 or higher or greater than 50% joint space narrowing on weight bearing flexion posterior-anterior radiographs)²⁶ were excluded. Age <40 years and BMI <35 kg/m² are commonly used criteria for consideration for cartilage restoration or replacement surgery; a total of 300 patients (63%) met these criteria for cartilage restoration surgery and 176 (37%) did not. An unequal distribution of athletes eligible for cartilage restoration surgery was observed by level of competition, with a greater percentage of ineligible patients among recreational athletes (48% ineligible) versus high school or collegiate competitive athletes (10% ineligible) ($P < 0.001$). To eliminate potential confounding and improve the clinical applicability of results, cartilage restoration-ineligible patients were excluded. After application of these criteria, the remaining 300 athletes (63% male, mean age 24.1 years, standard deviation [SD] 7.1; mean BMI 25.7 kg/m², SD 3.7) were included in the study for

further analysis. A total of 172 (57%) were recreational athletes and 128 (43%) were competitive athletes. An *a priori* power analysis was performed, and the study sample size was determined to be adequate to detect a mean 28-day difference in symptom duration, a 13% difference in high-grade defect prevalence and a mean 0.8 cm² difference in mean defect size with 80% power and $\alpha = 0.05$ between recreational and competitive athletes.

Lesion size, Outerbridge grade,²⁵ and number of lesions were documented by direct visualization during the diagnostic arthroscopic portion of the planned knee procedure. Clinical data including activity level, concomitant injuries, tobacco use status, and history of prior knee injuries or surgeries were obtained via medical record review. Symptom duration was defined as the time from symptom onset to day of surgery.

The majority of athletes in the cohort ($n = 196$ of 300) participated in either football ($n = 56$), basketball ($n = 52$), soccer ($n = 51$), or running (long distance running, cross country, or track and field) ($n = 37$) as their primary sporting activity. The remaining 104 athletes participated in the following sports in descending order: baseball or softball ($n = 15$), volleyball ($n = 12$), weightlifting ($n = 9$), biking ($n = 8$), dance ($n = 7$), ski or snowboarding ($n = 7$), martial arts ($n = 6$), and the remaining sports with less than 5 athletes per sport ($n = 40$ athletes, $n = 20$ sports). To allow for analysis across multiple sports, each sport was characterized according to type of activity including athlete-athlete contact (such as football and martial arts), repetitive ground impact (such as running or gymnastics), frequent cutting/pivoting (such as basketball and soccer), and endurance activities (such as running, swimming, or biking). For analysis of sport-specific risk factors, the analysis was restricted to athletes in the four most common sports (football, basketball, soccer, and running) to minimize risk of type 2 error from small sample sizes.

For the purpose of the current study, recreational athlete status was defined as habitual performance of a sporting activity at least 3 times per week either independently or in a recreational sporting league. Competitive athlete status was defined as performance of a sporting activity in a school-sponsored sport with regular participation in competitive sporting events. In the current study, all competitive athletes participated in high school or collegiate level team sports ($n = 128$, 100%).

Statistical Analysis

Statistical analysis was performed with a standard software package (STATA 13.0, College Station, TX). Descriptive statistics were first generated for the entire sample and after stratification by level of competition. Differences in categorical variables were assessed by Chi-square test. Differences in continuous variables were assessed via

Student *t* test or Wilcoxon rank sum for variables with normal versus nonnormal distributions, respectively.

The independent association between level of competition, type of sporting activity, and cartilage defect characteristics was determined via multivariate logistic regression analysis. To minimize risk of model overfitting, patient age and symptom duration were selected *a priori* as clinically important covariates with regard to cartilage damage. A Johnson SU transformation was performed for symptom duration to achieve a normal distribution; these transformed values were then used in the multivariate model.

Among athletes eligible for cartilage restoration surgery who participated in the 4 most common sports in the current study (basketball, football, running, and soccer) ($n = 196$ total), high-grade defect prevalence was compared by level of competition as well as by sport via chi-square test. Median duration of symptoms by sport and level of competition was compared by Wilcoxon rank-sum. Finally, the independent association between symptom duration, level of competition, and by sport was determined by multivariate linear regression.

Results

Demographic and Clinical Characteristics by Competitive Level and Eligibility for Cartilage Restoration

Recreational athletes were older and had a higher BMI than competitive athletes, but rates of tobacco use were low across all groups (**Table 3**). Recreational athletes were more likely to participate in endurance sports, whereas competitive athletes and cartilage restoration-eligible athletes were more likely to participate in athlete-athlete contact sports, impact sports, and cutting/pivoting sports (**Table 3**). There was a trend toward higher median duration of symptoms among recreational athletes (median 88 days) versus competitive athletes (median 67 days; $P = 0.10$) (**Table 3**). Recreational and competitive athletes had similar rates of concurrent meniscus and ligament procedures (**Table 3**).

Cartilage Defect Characteristics by Athlete Competitive Level

Full-thickness defects were present in 24% of competitive and 31% of recreational athletes ($P = 0.21$). High-grade (grade 3-4) multicompartments defects were uncommon among recreational (6%) and competitive athletes (5%; $P = 0.67$) (**Table 4**). There was no difference in grades 3 to 4 defect size (regardless of location) among recreational athletes (mean 2.4 cm², SD 2.4) versus competitive athletes (mean 2.3 cm², SD 2.2) ($P = 0.71$); and duration of symptoms did not correlate with high-grade defect size ($\beta = 0.14$, standard error [SE] 0.09; $P = 0.14$). At baseline, without

Table 3. Demographic and Clinical Differences Between Athletes and Nonathletes.

	Competitive Athletes (n = 128)	Recreational Athletes (n = 172)	P	All Athletes (n = 300)
Age, years, mean (SD)	18.9 (4.5)	27.9 (6.2)	<0.001	24.1 (7.1)
Sex, %				
Male	55	70	0.007	63
Female	45	30		37
BMI, kg/m ² , mean (SD)	25.0 (3.6)	26.2 (3.6)	0.007	25.7 (3.7)
Current smoker, %	7	11	0.29	10
Sport, n (%)				
Football	45 (35)	11 (6)	<0.001	56 (19)
Basketball	25 (20)	27 (16)		52 (17)
Soccer	18 (14)	33 (19)		51 (17)
Running	7 (5)	30 (17)		37 (12)
Other	33 (26)	71 (41)		104 (35)
Repetitive ground impact sport, %	96	80	<0.001	87
Athlete-athlete contact sport, %	39	11	<0.001	23
Endurance sport, %	6	23	<0.001	16
Cutting/pivoting sport, %	79	56	<0.001	66
Previous ipsilateral knee surgery, %	23	23	0.90	23
Time from symptom onset until day of surgery, days			0.10	
25th percentile	30	39		35
Median	67	88		79
75th percentile	223	262		259
Concurrent partial meniscectomy, %	56	59	0.60	58
Concurrent meniscus repair, %	24	22	0.67	23
Concurrent ACLR, %	39	42	0.63	41
Concurrent meniscus repair or ligament reconstruction, %	52	48	0.42	50

BMI = body mass index; ACLR = anterior cruciate ligament reconstruction.

Table 4. Cartilage Defect Characteristics.

	Competitive Athletes (n = 128)	Recreational Athletes (n = 172)	P	All Athletes (n = 300)
Highest grade defect, %				
Grade 2	62	55	0.43 ^a	58
Grade 3	14	14		14
Grade 4	24	31		28
Multicompartment grade 3-4 defects, %	5	6	0.67	5
Anterior grade 3-4 defect presence, %	23	21	0.66	22
Size, cm ² , mean (SD)	2.4 (2.4)	2.5 (1.9)	0.58 ^b	2.4 (2.1)
Anterior grade 4 defect presence, %	11	16	0.19	14
Size, cm ² , mean (SD)	2.2 (2.9)	2.3 (1.7)	0.29	2.3 (2.1)
Lateral grade 3-4 defect presence, %	13	16	0.43	14
Size, cm ² , mean (SD)	2.5 (2.4)	3.1 (3.3)	0.56 ^b	2.8 (3.0)
Lateral grade 4 defect presence, %	9	10	0.70	9
Size, cm ² , mean (SD)	2.0 (1.9)	2.8 (3.9)	0.66 ^b	2.5 (3.1)
Medial grade 3-4 defect presence, %	12	13	0.67	13
Size, cm ² , mean (SD)	1.8 (1.7)	3.0 (4.7)	0.70 ^b	2.5 (3.8)
Medial grade 4 defect presence, %	9	9	0.85	9
Size, cm ² , mean (SD)	1.9 (1.8)	2.6 (5.3)	0.50 ^b	2.3 (4.0)

^aCochran Armitage trend test.

^bWilcoxon rank-sum.

Table 5. Adjusted Association Between Athletic Status and Presence of High-Grade Cartilage Defects.

	Anterior Grade 3-4 Defect Presence	P	Lateral Grade 3-4 Defect Presence	P	Medial Grade 3-4 Defect Presence	P
Recreational athlete	1.0 (ref)	0.10	1.0 (ref)	0.94	1.0 (ref)	0.21
Competitive athlete	2.00, CI 0.86-4.62		0.97 CI 0.47, 2.02		1.81 CI 0.71, 4.65	
Repetitive ground impact	0.74, CI 0.28-1.96	0.54	2.46 CI 0.71, 8.51	0.15	1.91 CI 0.56, 7.00	0.29
Athlete-athlete contact	1.21, CI 0.56-2.66	0.62	0.33 CI 0.11, 0.97	0.04	0.72 CI 0.27, 1.91	0.51
Cutting/pivoting	2.11, CI 0.81-5.56	0.15	0.87 CI 0.33, 2.27	0.77	1.15 CI 0.51, 2.55	0.74
Endurance	2.14, CI 0.71-6.50	0.18	0.88 CI 0.28, 2.80	0.84	0.85 CI 0.24, 3.07	0.81
Age	1.07, CI 1.02-1.14	0.009	1.03 CI 0.97, 1.09	0.32	1.07 CI 1.01, 1.14	0.03
Symptom duration ^a	$\beta = 0.43$ (SE 0.16)	0.007	$\beta = 0.34$ (SE 0.18)	0.06	$\beta = 0.22$ (SE 0.18)	0.22

CI = confidence interval; SE = standard error.

^aJohnson's SU transformation applied to symptom duration to achieve a normal distribution for use in the multivariate analysis.

adjusting for confounders there was no difference in the prevalence or size of high-grade defects in the anterior, lateral, or medial compartments among recreational or competitive athletes (**Table 4**).

Independent Association between Athletic Status, Defect Size, and Multicompartment Disease Among Athletes Eligible for Cartilage Restoration

After adjusting for type of sporting activity, patient age, and duration of symptoms, there was a trend toward higher odds of high-grade anterior defects among competitive athletes (odds ratio [OR] 2.00, confidence interval [CI] 0.86-4.62; $P = 0.10$) but no association between competitive level and presence of high-grade lateral or medial compartment defects (**Table 5**). High-grade lateral compartment defects were less common among athletes in contact sports compared with noncontact sports (OR 0.33, CI 0.11-0.97; $P = 0.04$); otherwise there was no other identified association between defect presence and type of sporting activity (**Table 5**). There was a trend toward higher odds of multicompartment high-grade defects among competitive athletes (OR 3.99, CI 0.84-18.8; $P = 0.08$) but no association with type of sporting activity (**Table 6**).

Defect Characteristics among Basketball, Football, Running, and Soccer Athletes

Among athletes in the 4 most common sports in the current study ($n = 196$ total), no difference was observed in the presence of high-grade defects in any knee compartment between recreational ($n = 101$) and competitive level athletes ($n = 95$) (**Table 7**). The prevalence of multicompartment defects varied by sport, with the highest prevalence among runners (11%) followed by basketball (8%), soccer (4%), and football (0%) ($P = 0.04$). Similarly, the prevalence of high-grade (3-4) lateral defects varied by sport,

with a higher prevalence among runners (24%) followed by basketball (23%), soccer (18%), and football (5%) ($P = 0.02$). No difference in the prevalence of medial or anterior defects was observed across these sports.

Duration of Symptoms among Basketball, Football, Running, and Soccer Players Eligible for Cartilage Restoration

At baseline, runners had a significantly longer duration of symptoms (median 201 days) compared with basketball (88 days), football (43 days), and soccer players (50 days) ($P < 0.001$) (**Table 8, Fig. 1**). Competitive athletes from these sports had a shorter symptom duration (median 52 days) than recreational athletes (median 91 days) ($P = 0.006$) (**Table 8**). After adjusting for athlete age and level of competition, runners had the longest duration of symptoms (adjusted mean 198 days) followed by basketball (81 days), soccer (66 days), and football (51 days) ($P = 0.005$), with a trend toward shorter symptom duration among competitive athletes (adjusted mean 73 days) versus recreational athletes (adjusted mean 92 days) ($P = 0.08$) (**Table 9**). Duration of symptoms was not independently correlated with high-grade defect size among these sports ($\beta = 0.23$, SE 0.09; $P = 0.23$).

Discussion

Knee articular cartilage injuries are common in athletes, producing significant pain and functional limitations, although they may present differently by sporting activity and competition level. Cartilage restoration outcomes can vary by sporting activity and competitive level.^{17,18} However, it is difficult to determine whether this variability in outcomes is solely due to sport or competitive level-specific functional demands, or due to important baseline differences in cartilage lesion characteristics among athletic groups. In the current study, among patients who meet

Table 6. Adjusted Risk of Multicompartment Grade 3-4 Chondral Defects.

	Adjusted Odds Ratio, 95% Confidence Interval	P
Recreational athlete	1.0 (referent)	0.08
Competitive athlete	3.99, 0.84-18.8	
Repetitive ground impact	0.98, 0.18-9.46	0.98
Athlete-athlete contact	0.38, 0.04-3.38	0.39
Cutting-pivoting sport	0.73, 0.16-3.35	0.69
Endurance sport	0.74, 0.12-4.48	0.74
Age	Per year increase: 1.13, 1.02-1.25	0.003
Symptom duration ^a	$\beta = 0.94^b$ (SE 0.33)	0.005

CI = confidence interval; SE = standard error.

^aJohnson's Su transformation applied to symptom duration to achieve a normal distribution for use in the multivariate analysis.

^bA positive value for beta coefficient indicates that longer symptom duration increases the likelihood of a high-grade chondral defect.

Table 7. Defect Characteristics Among Basketball, Football, Running, and Soccer Athletes.

	Basketball (n = 52), %	Football (n = 56), %	Running (n = 37), %	Soccer (n = 51), %	P	Competitive Athlete (n = 95), %	Recreational Athlete (n = 101), %	P
Multicompartment grade 3-4 changes	8	0	11	4	0.04	6	4	0.58
Anterior grade 3-4 defects	23	21	27	20	0.87	23	22	0.91
Anterior grade 4 defects	15	9	16	16	0.64	16	12	0.39
Lateral grade 3-4 defects	23	5	24	18	0.02	20	14	0.25
Lateral grade 4 defects	14	2	22	12	0.02	14	8	0.22
Medial grade 3-4 defects	17	7	16	14	0.37	14	13	0.80
Medial grade 4 defects	12	5	14	12	0.50	11	9	0.74

Table 8. Mean Symptom Duration by Sport and Competitive Level among Basketball, Football, Running, and Soccer Athletes.

	Basketball (n = 52), Days	Football (n = 56), Days	Running (n = 37), Days	Soccer (n = 51), Days	P	Competitive (n = 95), Days	Recreational (n = 101), Days	P
25th percentile	35	28	83	30	<0.001	28	40	0.006
Median	88	43	201	50		52	91	
75th percentile	248	141	443	132		183	288	

demographic and radiographic criteria for cartilage restoration, athlete age and longer symptom duration were the most important predictors of high-grade defect presence at the time of knee arthroscopy, though a higher competitive level had a trend toward a greater prevalence of high-grade anterior compartment or multicompartment involvement. The duration of symptoms prior to arthroscopy was sports specific, and runners had substantially longer mean symptom duration prior to arthroscopy. The current study findings have important implications in the interpretation of cartilage treatment outcome studies in recreational and scholastic competitive athletes, as sport and competition level differences in lesion characteristics may correspondingly result in differences in treatment outcomes.

In the current study, increased age and symptom duration rather than competitive level and type of sporting

activity were the most important risk factors for presence of a high-grade cartilage defect in recreational and scholastic competitive athletes. This information can aid in interpretation of the existing knee cartilage defect literature and as well as identification of patients at high risk for having a high-grade defect. Type of sporting activity (impact sport, contact sport, cutting-pivoting, or endurance sport) did not influence risk of high-grade defect presence at time of arthroscopy, though competitive scholastic athletes had a trend toward higher likelihood of a high-grade anterior defect or multicompartment defects compared with recreational athletes in the fully adjusted statistical models (Tables 5 and 6). This is in contrast to studies including professional athletes, which often note a greater incidence of high-grade defects at high competitive levels.^{13,16}

Figure 1. Box plot of symptom duration by primary sporting activity. Symptom duration was defined as time between symptom onset and day of arthroscopic knee surgery. Runners presented with a significantly longer symptom interval (median 201 days) than basketball (median 88 days), football (median 43 days) or soccer players (median 50 days) ($P < 0.001$). The 25th percentiles, median, and 75th percentiles are represented by the lower border, inner band, and upper borders of the box, respectively. Dots outside of the crosshairs represent patients with outlier values greater than 1.0 interquartile distance (distance between 75th and 25th percentiles) above the 75th percentile. Values greater than 600 days were omitted for display purposes; no values were omitted from the statistical analyses.

Table 9. Independent Risk Factors of Delayed Presentation for Surgery among Basketball, Football, Running, and Soccer Athletes.

	β Coefficient ^a (SE)	P	Adjusted Mean Symptom Duration, Days
Recreational athlete	Referent	0.08	92
Competitive athlete	-0.23 (0.11)		73
Basketball	Referent	0.005	81
Football	-0.35 (0.14)		51
Running	0.48 (0.17)		198
Soccer	-0.17 (0.14)		66
Age	0.01 (0.01)	0.43	N/A

SE = standard error; N/A = not applicable.

^aA positive β coefficient indicates the variable is independently associated with a longer duration of symptoms prior to knee arthroscopy. A negative β coefficient indicates the variable is independently associated with a shorter duration of symptoms prior to knee arthroscopy.

Symptomatic high-grade lateral defects were more common than medial defects in the current study, specifically among runners, basketball players, and soccer players. The current study suggests a higher rate of high-grade symptomatic lateral lesions in recreational and scholastic competitive athletes in sports with repetitive running activities than is suggested by reports that include professional or asymptomatic athletes. Flanigan *et al.*¹³ reported a higher prevalence of medial (24%) than lateral (11%) femoral condyle chondral lesions, though studies of professional-level athletes as well as asymptomatic athletes were included in the review. Andrade *et al.*¹⁵ similarly report a higher prevalence of cartilage lesions in the medial femoral condyle than the lateral femoral condyle in professional soccer players, though this study also

included asymptomatic athlete. Awareness of the relatively high prevalence of symptomatic high-grade lateral defects in certain athletic populations is helpful when selecting treatment, as lateral high-grade lesions can have less symptom relief long-term than medial lesions with therapies such as microfracture.²⁷

Among athletes, cartilage restoration of smaller defects tends to have better outcomes,¹ and no difference was found in the current study in high-grade defect size (regardless of location) among recreational athletes (mean 2.4 cm², SD 2.4) versus competitive scholastic athletes (mean 2.3 cm², SD 2.2). Furthermore, symptom duration was not significantly correlated with high-grade defect size in the current study. The mean defect size identified in the current study corresponds with the results of Blevins *et al.*²⁸ (mean 2.23

cm², SD 1.80) for symptomatic recreational and competitive athletes with high-grade cartilage defects treated with microfracture; they similarly found no difference in defect size by competitive level. Similarly, in a series of 993 consecutive knee arthroscopies, 55% of full-thickness defects were greater than 2 cm² in size.²⁹

Chronic cartilage defects in athletes tend to respond less well to treatment,¹ and symptom chronicity varied significantly by sport as well as competitive level in the current study. Recreational athletes and runners in particular had a longer symptom duration prior to arthroscopy; this can potentially influence treatment outcomes as longer symptom chronicity is associated with worse outcomes following cartilage defect treatment in athletes,^{1,27} even in adolescent populations.³⁰ It is possible that runners may tolerate chondral injuries longer than soccer, football, or basketball players due to a lack of rapid stop-start movements, as return to rapid stop-start movements following cartilage restoration is not as well tolerated as return to endurance activities.¹⁹ The association between higher competitive level and shortened symptom duration could be due to earlier recognition of symptoms in the setting of higher knee functional demands as well as greater proprioceptive acuity seen in competitive experienced athletes.³¹

Limitations

The study has several strengths and limitations. The vast majority of athletes in the United States are recreational or scholastic level competitive athletes. The current study results are representative of the athletic population treated in most sports medicine practices in the region. Additionally, the current study was restricted to symptomatic athletes who meet age, BMI, and radiographic criteria (<50% joint space narrowing on weightbearing radiographs) for cartilage restoration. Arthroscopic evaluation of symptomatic cartilage defects remains superior to magnetic resonance imaging, as the latter has lower sensitivity³² and tends to underestimate lesion size.³³

The current study results may not be applicable to professional athletes or athletes that participate in sports underrepresented in the current analysis. Because of external pressures to perform, professional athletes may present later with more advanced disease and longer duration of symptoms. The study findings are not applicable to an asymptomatic athletic population, as characteristics of symptomatic defects may differ from asymptomatic defects. In addition, the number of patients included in the present study is relatively small. Thus, widespread application of conclusions may not be appropriate. Furthermore, no specific analysis of clinical outcomes scores was performed as this was a retrospective study with no prospective collection of patient outcomes data. In addition, the present study did not control for concomitant injuries treated at the same

time as cartilage restoration such as meniscal pathology. Finally, no comparison was made between gender, thus further limiting the application of study conclusions to specific patient populations.

Conclusions

Among recreational and high school or collegiate competitive athletes with symptomatic cartilage defects who meet age and BMI criteria for cartilage restoration, competitive athletes may have higher risk of high-grade anterior and multicompartments defects but no difference in defect size. High-grade defect prevalence and location is sport specific, as is the average duration of symptoms prior to initial arthroscopic surgery.

Acknowledgments and Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The authors received no funding for this study and report no conflicts of interest. David C. Flanigan receives funding from Depuy Mitek, Inc., Smith & Nephew, Vericel, Ceterix Orthopaedics, Conmed, Histogenics Corporation, and Zimmer Inc.

Ethical Approval

This project was approved by the Biomedical Institutional Research Board of The Ohio State University.

References

1. Campbell AB, Pineda M, Harris JD, Flanigan DC. Return to sport after articular cartilage repair in athletes' knees: a systematic review. *Arthroscopy*. 2016;32:651-68.e1.
2. Niethammer TR, Holzgruber M, Gülecü MF, Weber P, Pietschmann MF, Müller PE. Matrix based autologous chondrocyte implantation in children and adolescents: a match paired analysis in a follow-up over three years post-operation. *Int Orthop*. 2017;41:343-50.
3. Heir S, Nerhus TK, Røtterud JH, Løken S, Ekeland A, Engebretsen L, *et al*. Focal cartilage defects in the knee impair quality of life as much as severe osteoarthritis: a comparison of knee injury and osteoarthritis outcome score in 4 patient categories scheduled for knee surgery. *Am J Sports Med*. 2010;38:231-7.
4. Clar C, Cummins E, McIntyre L, Thomas S, Lamb J, Bain L, *et al*. Clinical and cost-effectiveness of autologous chondrocyte implantation for cartilage defects in knee joints: systematic review and economic evaluation. *Health Technol Assess*. 2005;9:iii-iv,ix-x,1-82.
5. DiBartola AC, Everhart JS, Magnussen RA, Carey JL, Brophy RH, Schmitt LC, *et al*. Correlation between histological

- outcome and surgical cartilage repair technique in the knee: a meta-analysis. *Knee*. 2016;23:344-9.
6. Roemer FW, Kwok CK, Hannon MJ, Green SM, Jakicic JM, Boudreau R, *et al*. Risk factors for magnetic resonance imaging-detected patellofemoral and tibiofemoral cartilage loss during a six-month period: the joints on glucosamine study. *Arthritis Rheum*. 2012;64:1888-98.
 7. Roemer FW, Felson DT, Wang K, Crema MD, Neogi T, Zhang Y, *et al*. Co-localisation of non-cartilaginous articular pathology increases risk of cartilage loss in the tibiofemoral joint—the MOST study. *Ann Rheum Dis*. 2013;72:942-8.
 8. Cicuttini F, Ding C, Wluka A, Davis S, Ebeling PR, Jones G. Association of cartilage defects with loss of knee cartilage in healthy, middle-age adults: a prospective study. *Arthritis Rheum*. 2005;52:2033-9.
 9. Ding C, Cicuttini F, Scott F, Boon C, Jones G. Association of prevalent and incident knee cartilage defects with loss of tibial and patellar cartilage: a longitudinal study. *Arthritis Rheum*. 2005;52:3918-27.
 10. Roemer FW, Zhang Y, Niu J, Lynch JA, Crema MD, Marra MD, *et al*. Tibiofemoral joint osteoarthritis: risk factors for MR-depicted fast cartilage loss over a 30-month period in the multicenter osteoarthritis study. *Radiology*. 2009;252:772-80.
 11. Carnes J, Stannus O, Cicuttini F, Ding C, Jones G. Knee cartilage defects in a sample of older adults: natural history, clinical significance and factors influencing change over 2.9 years. *Osteoarthritis Cartilage*. 2012;20:1541-7.
 12. Guermazi A, Hayashi D, Roemer FW, Niu J, Quinn EK, Crema MD, *et al*. Brief report: partial- and full-thickness focal cartilage defects contribute equally to development of new cartilage damage in knee osteoarthritis: the Multicenter Osteoarthritis Study. *Arthritis Rheumatol*. 2017;69:560-4.
 13. Flanigan DC, Harris JD, Trinh TQ, Siston RA, Brophy RH. Prevalence of chondral defects in athletes' knees: a systematic review. *Med Sci Sports Exerc*. 2010;42:1795-801.
 14. Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE. A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech (Bristol, Avon)*. 2001;16:438-45.
 15. Andrade R, Vasta S, Papalia R, Pereira H, Oliveira JM, Reis RL, *et al*. Prevalence of articular cartilage lesions and surgical clinical outcomes in football (soccer) players' knees: a systematic review. *Arthroscopy*. 2016;32:1466-77.
 16. Kaplan LD, Schurhoff MR, Selesnick H, Thorpe M, Uribe JW. Magnetic resonance imaging of the knee in asymptomatic professional basketball players. *Arthroscopy*. 2005;21:557-61.
 17. Harris JD, Brophy RH, Siston RA, Flanigan DC. Treatment of chondral defects in the athlete's knee. *Arthroscopy*. 2010;26:841-52.
 18. Pánics G, Hangody LR, Baló E, Vászrhelyi G, Gál T, Hangody L. Osteochondral autograft and mosaicplasty in the football (soccer) athlete. *Cartilage*. 2012;3(1 Suppl):25S-30S.
 19. Pestka JM, Feucht MJ, Porichis S, Bode G, Südkamp NP, Niemeyer P. Return to sports activity and work after autologous chondrocyte implantation of the knee: which factors influence outcomes? *Am J Sports Med*. 2016;44:370-7.
 20. Steadman JR, Hanson CM, Briggs KK, Matheny LM, James EW, Guillet A. Outcomes after knee microfracture of chondral defects in alpine ski racers. *J Knee Surg*. 2014;27:407-10.
 21. Gudas R, Gudaite A, Pocius A, Gudiene A, Cekanauskas E, Monastyreckiene E, *et al*. Ten-year follow-up of a prospective, randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint of athletes. *Am J Sports Med*. 2012;40:2499-508.
 22. Panagopoulos A, van Niekerk L, Triantafillopoulos I. Autologous chondrocyte implantation for knee cartilage injuries: moderate functional outcome and performance in patients with high-impact activities. *Orthopedics*. 2012;35:e6-14.
 23. Kon E, Filardo G, Berruto M, Benazzo F, Zanon G, Villa SD, *et al*. Articular cartilage treatment in high-level male soccer players: a prospective comparative study of arthroscopic second-generation autologous chondrocyte implantation versus microfracture. *Am J Sports Med*. 2011;39:2549-57.
 24. McCarthy MA, Meyer MA, Weber AE, Levy DM, Tilton AK, Yanke AB, *et al*. Can competitive athletes return to high-level play after osteochondral allograft transplantation of the knee? *Arthroscopy*. 2017;33:1712-7.
 25. Outerbridge RE. The etiology of chondromalacia patellae. *J Bone Joint Surg Br*. 1961;43-B:752-7.
 26. Kellgren JH, Lawrence JS. Radiological assessment of osteoarthritis. *Ann Rheum Dis*. 1957;16:494-502.
 27. Gobbi A, Karnatzikos G, Kumar A. Long-term results after microfracture treatment for full-thickness knee chondral lesions in athletes. *Knee Surg Sports Traumatol Arthrosc*. 2014;22:1986-96.
 28. Blevins FT, Steadman JR, Rodrigo JJ, Silliman J. Treatment of articular cartilage defects in athletes: an analysis of functional outcome and lesion appearance. *Orthopedics*. 1998;21:761-8.
 29. Arøen A, Løken S, Heir S, Alvik E, Ekeland A, Granlund OG, *et al*. Articular cartilage lesions in 993 consecutive knee arthroscopies. *Am J Sports Med*. 2004;32:211-5.
 30. Mithöfer K, Minas T, Peterson L, Yeon H, Micheli LJ. Functional outcome of knee articular cartilage repair in adolescent athletes. *Am J Sports Med*. 2005;33:1147-53.
 31. Han J, Waddington G, Anson J, Adams R. Level of competitive success achieved by elite athletes and multi-joint proprioceptive ability. *J Sci Med Sport*. 2015;18:77-81.
 32. Figueroa D, Calvo R, Vaisman A, Carrasco MA, Moraga C, Delgado I. Knee chondral lesions: incidence and correlation between arthroscopic and magnetic resonance findings. *Arthroscopy*. 2007;23:312-5.
 33. Campbell AB, Knopp MV, Kolovich GP, Wei W, Jia G, Siston RA, *et al*. Preoperative MRI underestimates articular cartilage defect size compared with findings at arthroscopic knee surgery. *Am J Sports Med*. 2013;41:590-5.