Association of Body Mass Index With Severity and Lesion Location in Adolescents With Osteochondritis Dissecans of the Knee

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Background: The association between body mass index (BMI) and severity of osteochondritis dissecans (OCD) of the knee at presentation is poorly understood.

Hypothesis: We hypothesized that adolescents in higher BMI percentiles for age and sex would have OCD lesions that were more severe at their initial presentation and located more posteriorly on the condyle as compared with adolescents in lower BMI percentiles.

Study Design: Cohort study; Level of evidence, 3.

Methods: This study included patients aged 10 to 18 years who were treated for knee OCD at a tertiary care hospital from 2006 to 2017. Patients with noncondylar OCD or missing BMI data within 3 months of presentation were excluded. Patients were stratified per the Centers for Disease Control and Prevention guidelines as underweight, normal weight, overweight, or obese, and the groups were compared according to age, side of lesion, 4 markers of lesion severity (cystic changes, loose fragments, subchondral fluid, and subchondral edema), and surgical treatment. Lesion angle was measured in reference to a line parallel to the femoral axis drawn through the center of a best-fit circle covering the distal condyle. Data were analyzed using chi-square tests, relative risk, Student *t* tests, analysis of variance, and linear regression of cumulative running percentages. Bonferroni correction was performed when applicable.

Results: A total of 77 patients met our inclusion criteria (mean age, 14.2 years; range, 10.1-18.8): 2 were underweight, 50 had normal BMI, 13 were overweight, and 12 were obese. We found correlations between BMI percentile and surgical treatment ($R^2 = .732$), subchondral fluid ($R^2 = .716$), subchondral edema ($R^2 = .63$), loose fragments ($R^2 = .835$), and the presence of at least 1 marker of lesion severity ($R^2 = .857$) ($P < .0001$ for all). No correlation was observed for cystic changes ($R^2 = .026$). There were significant associations between BMI ≥80th percentile and subchondral edema (risk ratio, 2.5; 95% CI, 1.3-4.8), medial condylar lesions (risk ratio, 1.3; 95% CI, 1.01-1.7), and lesions more anterior on the condyle ($P < .05$).

Conclusion: Higher BMI in adolescents was strongly correlated with multiple markers of severity of knee OCD at initial presentation as well as with more anterior lesions.

Keywords: adolescent; angle of incidence; body mass index; obesity; osteochondritis dissecans; pediatrics; severity

Osteochondritis dissecans (OCD) involves the disruption of subchondral bone and, secondarily, the overlying articular cartilage.[13] The pathophysiology of OCD suggests that areas of bone that are supplied by distal vasculature can experience a relative insufficiency of blood flow. These watershed areas can be more susceptible to the development of OCD under conditions of chronic overloading, such as that caused by obesity.[1,18] Childhood obesity, which has become more prevalent in recent years,[21] plays a role in the development of various musculoskeletal diseases, but its association with OCD is poorly understood. Because OCD can lead to arthritis in pediatric patients,[9] it is important to identify whether obesity is a modifiable risk factor for OCD.

Obesity increases the joint-loading forces in the knee,[2] and alterations in load-bearing forces influence OCD development.[7,16] The alterations in forces at the knee caused by obesity may be a form of repetitive trauma that predisposes patients to OCD. Higher body mass index (BMI) is associated with higher absolute tibiofemoral compression.[8] A motion-analysis study revealed that in patients with obesity, disproportionate stress is borne by forces spread over a smaller portion of the overall articular surface.[17] Biomechanical gait studies of the knee have shown that patients with obesity spend more time in the stance phase and loading the knee.[22] These 3 factors—higher compression forces, smaller areas of loading, and more loading time during

The Orthopaedic Journal of Sports Medicine, 9(9), 23259671211045382
DOI: 10.1177/23259671211045382

gait—may all influence OCD development in patients with obesity. Furthermore, alterations in loadbearing change the location of OCD lesions. Kajiyama et al[10] showed that humeral capitellum lesions in young athletes were more anterior in baseball players than in gymnasts because of differences in force distribution throughout the joint during their respective actions. Obesity is associated with increased knee flexion at initial contact during ambulation and significantly higher medial compartment loading.[15,22] The alterations in biomechanical forces caused by high BMI could cause lesions to develop in different areas than in patients with normal BMI. Thus, obesity may influence the presentation of OCD in the pediatric knee.

The association of BMI with the long-term prognosis of OCD has been studied. It is widely accepted that BMI above the normal range is associated with poorer treatment outcomes in patients with OCD of the knee.[5,12,19] However, these studies have focused on posttreatment outcomes. Until recently, the association of BMI with the incidence of OCD was unknown. In a population study, Kessler et al[11] found associations between high BMI and OCD of the knee, ankle, and elbow. Given the high prevalence of childhood obesity in the United States,[21] it is important to understand how BMI affects OCD, particularly the severity of OCD at presentation.

Our primary aim was to investigate the relationship between BMI percentile (for age and sex) and severity of OCD lesions in the femoral condyles at presentation. Our secondary aim was to examine the associations between BMI percentile and the location of femoral condylar OCD lesions, defined as laterality and angle of incidence. We hypothesized that patients in higher BMI percentiles would have OCD lesions that were more severe at initial presentation and located more posteriorly on the condyle as compared with patients in lower BMI percentiles.

METHODS

Study Population

We retrospectively reviewed data of all 269 patients aged 10 to 18 years who were treated for OCD of the knee (identified using hospital billing codes) at our academic urban tertiary care hospital from 2006 to 2017. After the exclusion of patients with OCD in locations other than the femoral condyle (eg, talar, capitellar, trochlear, and patellar) and those for whom BMI data were unavailable within 3 months of initial presentation, 77 patients (29%) were included in our study (Figure 1). This study was approved by our institutional review board.

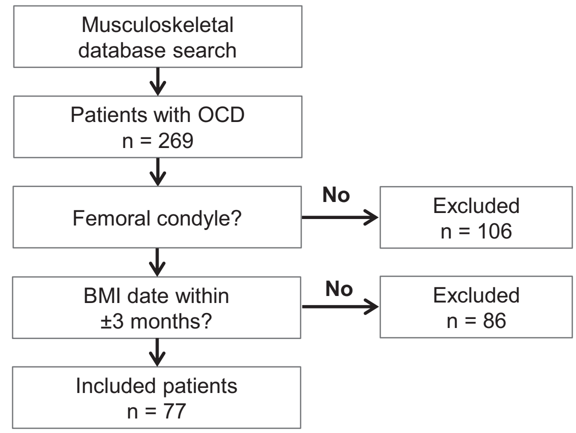

Figure 1. Patient-selection flowchart. Of the initial study population, 77 patients were included in the analysis of markers of lesion severity. Radiographic measurements were available for 61 patients, who were included in the analysis of the angle-of-lesion incidence. BMI, body mass index; OCD, osteochondritis dissecans.

We collected data on patient characteristics from clinical notes. The mean ± SD age at presentation was 14 ± 2.2 years. Most patients were White (n = 54; 70%), whereas 22 (29%) were Black and 1 (1%) was identified as Other. Most patients were male (n = 55; 71%). The mean BMI was 22.1 ± 5.21 (range, 13.0-38.3).

We used the following Centers for Disease Control and Prevention BMI categories[3] based on percentile for age and sex: underweight (<5th percentile), normal weight (5th to <85th), overweight (85th to <95th), and obese (≥95th). Accordingly, 2 patients (3%) were underweight, 50 (65%) normal weight, 13 (17%) overweight, and 12 (16%) obese.

All measurements and calculations obtained from patient imaging were reviewed for consistency and accuracy by the senior author.

Lesion Severity

Using radiographic and magnetic resonance imaging, when available, we collected data on lesion characteristics and laterality. We also recorded surgical treatment and other markers of lesion severity, including cystic changes surrounding the lesion, the presence of loose fragments, edema at the osteochondral fragment and adjacent bone interface, and a break in the subchondral plate with fluid tracking through.[4]

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Final revision submitted May 14, 2021; accepted June 23, 2021.

One or more of the authors has declared the following potential conflict of interest or source of funding: Research grants were received from Arthrex and OrthoPediatrics and support for clinical trial participation from Vericel. R.J.L. has received education payments from Arthrex and Supreme Orthopedics Systems and hospitality payments from Vericel. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from John Hopkins Medicine (IRB00152963)

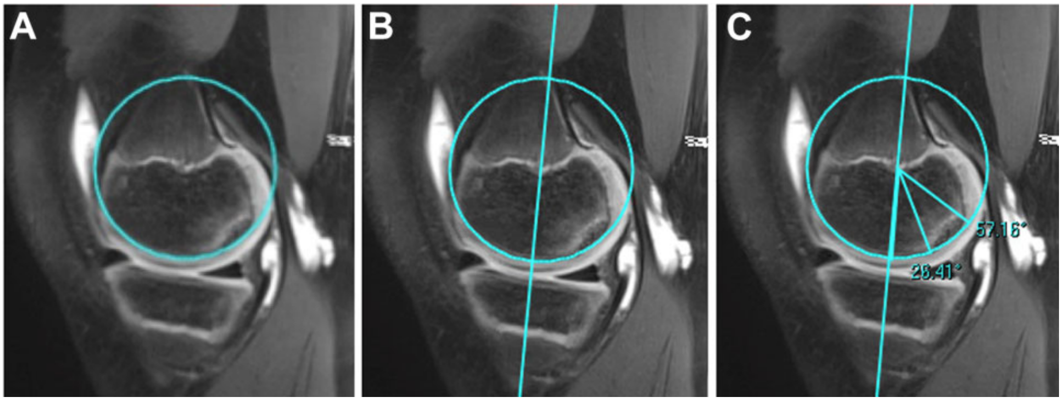

Figure 2. Radiographs showing steps taken to measure the angle of osteochondritis dissecans lesion on the femoral condyle. (A) A best-fit circle was applied to the distal femoral condyles, typically with the center of the circle resting on the epiphyseal plate. (B) The anatomic femoral shaft axis was determined using the anterior and posterior femoral cortices as references, and a line parallel to this axis was drawn through the center of the best-fit circle. (C) Angle measurements anterior to this line were recorded as negative and measurements posterior as positive.

Lesion Location

Patients who did not have radiographic or magnetic resonance imaging available were excluded from this subgroup analysis. The angle of incidence of the OCD lesions was determined on the basis of sagittal plane imaging. First, a best-fit circle was applied to the distal femoral condyles (Figure 2A). Then, the anatomic femoral shaft axis was determined, and a line parallel to this axis was drawn through the center of the best-fit circle (Figure 2B). The angle of the line was measured from the center of the circle to the anterior- and posterior-most extensions of the lesion in relation to the line parallel to the anatomic axis (Figure 2C). The angle of incidence of the lesion was calculated by averaging the measurement of the posterior- and anterior-most angles of the lesion.

Statistical Analysis

We calculated and plotted cumulative running percentages for each marker of severity as well as surgical treatment. Analysis of individual cumulative running percentages was performed using linear regression. We analyzed the significance for each variable using chi-square tests among BMI percentile groups, and we calculated risk ratios (RRs) among BMI percentile groups. Analysis of angle-of-lesion measurements was performed using analysis of variance and Student *t* tests. Multivariate regression analysis was performed for all variables of severity and angle-of-lesion measurements, taking into account patient sex and race. $P < .05$ was considered significant; Bonferroni correction was applied when appropriate as a post hoc analysis for significant findings. Stata software Version 15.1 (StataCorp) was used for analysis.

Additionally, we identified an inflection point at the 80th BMI percentile for all markers of lesion severity. Therefore, we stratified patients by using the 80th BMI percentile as a threshold (Table 1) and performed secondary analysis as described.

RESULTS

Patient Characteristics

Mean BMI percentile was 63 ± 3.4, with a significant difference according to patient sex (female, 51 ± 7.2; male, 68 ± 3.6; $P < .05$). Chi-square analysis showed no significant difference according to sex for any variables of severity, and *t* tests for angle-of-lesion location showed no significant difference ($P = .32$). No significant difference was found for BMI percentile by patient race (White, 59 ± 30; Black, 74 ± 26; $P = .10$). Chi-square analysis showed no difference between races for any variables of severity, and *t* tests for angle-of-lesion location showed no significant difference ($P = .91$). Multivariate regression analysis for variables of severity showed no significant differences when assessing race and sex.

Lesion Severity

Using linear regression, we found significant correlations between BMI percentile and subchondral edema ($R^2 = 0.630$), subchondral fluid ($R^2 = 0.716$), loose fragments ($R^2 = 0.695$), and surgical treatment ($R^2 = 0.732$) (all, $P < .0001$) (Figure 3). The presence of cystic changes decreased steadily from the 50th to 100th BMI percentiles, although no significant correlation was observed ($R^2 = 0.026$; $P = .498$). We found a significant correlation between increasing BMI percentile and the presence of at least 1 marker of lesion severity ($R^2 = 0.857$; $P < .0001$).

Chi-square analysis did not demonstrate significance for any variable when comparing across all 3 groups (Table 2). The combined overweight/obese group did not differ significantly in the proportion of patients treated surgically when compared with the normal-weight group (RR, 1.1; 95% CI, 0.82-1.6).

When compared with patients whose BMI values were below the 80th percentile, those with BMI values at or

TABLE 1
Markers of Lesion Severity and Location for 77 Adolescents With Osteochondritis Dissecans of the Knee, Stratified by BMI Threshold of the 80th Percentile[a]

	Percentile, No. (%)				
	<80th (n = 46)	≥80th (n = 31)	χ^2 Statistic[b]	*P* Value[c]	RR (95% CI)
Surgical treatment	26 (57)	24 (77)	3.5	.06	1.4 (0.99-1.9)
Marker of severity					
Cystic changes	16 (35)	10 (32)	0.05	.82	0.93 (0.49-1.8)
Loose fragments	9 (20)	8 (26)	0.42	.52	1.3 (0.57-3.0)
Subchondral edema	10 (22)	17 (55)	8.9	**<.01**	2.5 (1.3-4.8)
Subchondral fluid	22 (48)	21 (68)	3.0	.08	1.4 (0.94-2.0)
Lesion location					
Bilateral condyles	8 (17)	7 (23)	0.32	.57	1.3 (0.52-3.2)
Lateral condyle	15 (33)	4 (13)	3.9	.071	2.1 (0.14-1.1)
Medial condyle	31 (67)	27 (87)	3.9	**.049**	1.3 (1.01-1.7)

[a]BMI percentile for age and sex according to the Centers for Disease Control and Prevention.[3] BMI, body mass index; RR, risk ratio.
[b]For all, $df = 1$ and N = 77.
[c]Bold *P* values indicate statistically significant difference between patient groups ($P < .05$).

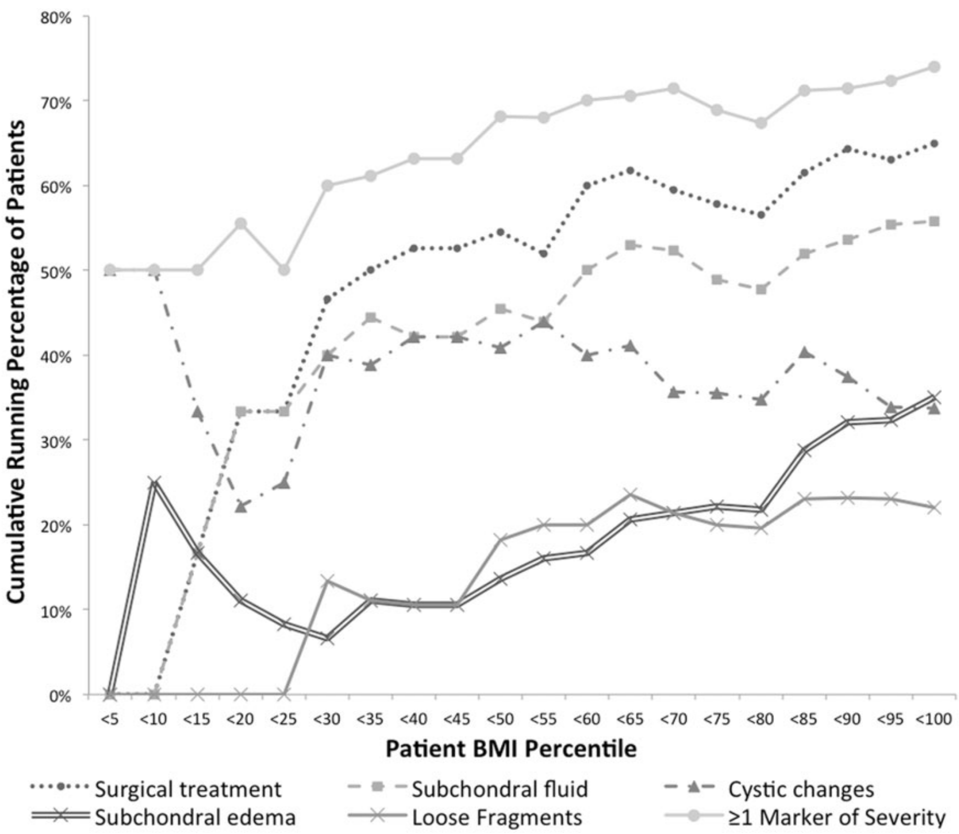

Figure 3. Markers of severity vs body mass index (BMI) percentiles. The cumulative percentage of each marker of lesion severity was plotted according to BMI percentile. Linear regression analysis showed significant correlations between higher BMI and presence of ≥1 marker of lesion severity, subchondral edema, subchondral fluid, loose fragments, and surgical treatment. We found no correlation between BMI and cystic changes, although cystic changes was the only variable that decreased overall with increasing BMI.

above the 80th percentile were significantly more likely to have subchondral edema ($\chi^2 = 8.9$ [$P < .01$]; RR, 2.5 [95% CI, 1.3-4.8]), even after applying Bonferroni correction. We found no significant differences between these groups in the presence of loose fragments, subchondral fluid, cystic changes, or surgical treatment ($P = .06$).

TABLE 2
Chi-square Analysis for Each Variable by BMI Category[a]

	Across All Groups		Normal vs Overweight/Obese	
	χ^2 Statistic[b]	*P* Value	χ^2 Statistic[c]	*P* Value
Surgical treatment	0.57	.75	0.48	.49
Marker of severity				
Cystic changes	4.9	.09	3.0	.08
Loose fragments	0.30	.86	0.15	.70
Subchondral edema	2.4	.30	2.3	.13
Subchondral fluid	0.98	.61	0.68	.41
Lesion location				
Bilateral condyles	1.2	.56	0.38	.54
Lateral condyle	3.8	.15	3.5	.06
Medial condyle	3.8	.15	3.5	.06

[a]BMI percentile for age and sex according to the Centers for Disease Control and Prevention.[3] BMI, body mass index.
[b]For all, $df = 2$ and n = 75.
[c]For all, $df = 1$ and n = 75.

TABLE 3
Angle of Lesion for 61 Adolescents With Osteochondritis Dissecans of the Knee by BMI Category[a]

BMI Category	No.	Angle, deg[b]	*P* Value[c]
Normal weight	38	21 ± 17	
Overweight	9	15 ± 15	.47
Obese	12	14 ± 18	.19
Combined overweight/obese	21	14 ± 16	.13
All patients[d]	61	18 ± 17	

[a]BMI categories determined according to the Centers for Disease Control and Prevention percentiles for age and sex: normal, 5th to <85th percentile; overweight, 85th to <95th; and obese, ≥95th.[3] BMI, body mass index.
[b]Positive measurements are indicated in reference to angles posterior to the reference line parallel to the femoral shaft axis (see Figure 2). Values are presented as mean ± SD.
[c]Compared with normal-weight group.
[d]Includes 2 underweight patients.

Lesion Location

Radiographic measurements of angle-of-lesion incidence were available for 61 of 77 patients (Table 3). Analysis of variance did not show significance for angle-of-lesion incidence when comparing across all BMI categories (F [2, 56] = 1.18; P = .32). We found no significant difference in the angle-of-lesion incidence between the combined overweight/obese group and the normal-weight group using a Student t test (P = .13). The combined overweight/obese group did not have a significantly higher proportion of medial lesions than the normal-weight group ($\chi^2 = 3.5$; P = .06), although the RR of 1.6 (95% CI, 1.0-1.6) suggested a positive relationship. We found no significant difference in the proportions of lateral or bilateral lesions (Table 4).

As compared with patients with BMI values <80th percentile, those with BMI values ≥80th were significantly more likely to have lesions located more anteriorly on the condyle (22.5° ± 17.0° vs 13.4° ± 14.5°, respectively; P = .03) and on the medial femoral condyle ($\chi^2 = 3.9$ [P = .049]; RR, 1.3 [95% CI, 1.01-1.7]). No differences were found in the presence of lesions on the lateral femoral condyle or the presence of bilateral lesions (Figure 4).

DISCUSSION

Adolescents with a BMI greater than the 80th percentile had more severe knee OCD at presentation, were more likely to have OCD on the medial condyles, and were more likely to have OCD lesions located anteriorly on the femoral condyle than adolescents in lower BMI percentiles.

We found that higher BMI percentiles were associated with increased severity of OCD at presentation. Higher BMI percentiles were correlated with the presence of multiple markers of lesion severity, including significant findings for subchondral edema. Furthermore, the absolute number of markers of severity per patient was positively correlated with increasing BMI percentile. When analyzing BMI percentile as a continuous variable, we found a correlation between increasing BMI percentile and 3 markers of severity, while cystic changes decreased as BMI percentile increased. Previous research shows that patients with high BMI values have worse treatment outcomes and long-term prognosis of OCD of the knee. A series of 86 patients with OCD of the knee showed that patients with BMI values >25 had greater risk of postoperative arthritis than patients with BMI values <25.[19] A prospective study of 224 adult patients showed that BMI was an independent predictor of failure of osteochondral allograft transplantations of the knee for treatment of OCD at 5-year follow-up.[5] These post-treatment findings complement our pretreatment findings, suggesting that higher BMI may negatively influence OCD throughout the disease process.

We also identified a trend in which OCD lesions were more likely to be on the medial femoral condyle and more anterior in patients with higher BMI values. These findings may be explained by altered biomechanics in the lower extremities in the setting of high BMI. However, this was contrary to our initial hypothesis that increased loading during knee flexion would be associated with more posterior lesions and higher BMI values. In terms of the medial femoral condyle location, a cadaveric study showed that weightbearing loads that simulated a BMI ≥30 created increased forces on medial femoral condyle cartilage defects.[14] A study evaluating obesity and walking duration found that total load passing through the medial compartment during stance was 83%, increasing to 90% during stance after a period of walking in children with obesity, whereas children of normal weight were more balanced at 63% and 72%.[15] Both studies suggest that obesity is associated with increased medial compartment load, which correlates with our findings of the medial femoral condyle location. Over the long term, these mechanics may influence the prognosis of OCD as found in the previously mentioned studies. Interestingly, studies have

TABLE 4
Markers of Lesion Severity and Location for 77 Adolescents With Osteochondritis Dissecans of the Knee by BMI Category [a]

	Patients, No. (%)		Overweight (n = 13)		Obese (n = 12)		Overweight/Obese (n = 25)	
	All (N = 77)[b]	Normal Weight (n = 50)	No. (%)	RR (95% CI)[b]	No. (%)	RR (95% CI)[b]	No. (%)	RR (95% CI)[c]
Surgical treatment	50 (65)	32 (64)	9 (69)	1.1 (0.71-1.6)	9 (75)	1.2 (0.80-1.7)	18 (72)	1.1 (0.81-1.6)
Marker of severity								
Cystic changes	26 (34)	20 (40)	1 (7.7)	0.19 (0.03-1.2)	4 (33)	0.83 (0.35-2.0)	5 (20)	0.5 (0.21-1.2)
Loose fragments	17 (22)	12 (24)	2 (15)	0.64 (0.16-2.5)	2 (17)	0.69 (0.18-2.7)	5 (20)	0.83 (0.33-2.1)
Subchondral edema	27 (35)	15 (30)	6 (46)	1.5 (0.68-3.0)	6 (50)	1.7 (0.82-3.4)	12 (48)	0.71 (0.89-2.9)
Subchondral fluid	43 (56)	27 (54)	9 (69)	1.3 (0.75-1.9)	7 (58)	1.1 (0.63-1.9)	16 (64)	1.2 (0.80-1.8)
Lesion location								
Bilateral condyles	15 (20)	9 (18)	4 (31)	1.7 (0.62-4.7)	2 (17)	0.93 (0.23-3.7)	6 (24)	1.3 (0.53-3.3)
Lateral condyle	19 (25)	16 (32)	1 (7.7)	0.24 (0.04-1.6)	2 (17)	0.52 (0.14-2.0)	3 (12)	2.0 (0.12-1.2)
Medial condyle	58 (75)	34 (68)	12 (92)	1.4 (0.95-1.7)	10 (83)	1.2 (0.89-1.7)	22 (88)	1.6 (1.0-1.6)

[a]BMI categories determined according to the Centers for Disease Control and Prevention percentiles for age and sex: normal weight, 5th to <85th percentile; overweight, 85th to <95th; and obese, ≥95th.[3] BMI, body mass index; RR, risk ratio.
[b]Includes 2 underweight patients.
[c]RR compared with normal-weight group.

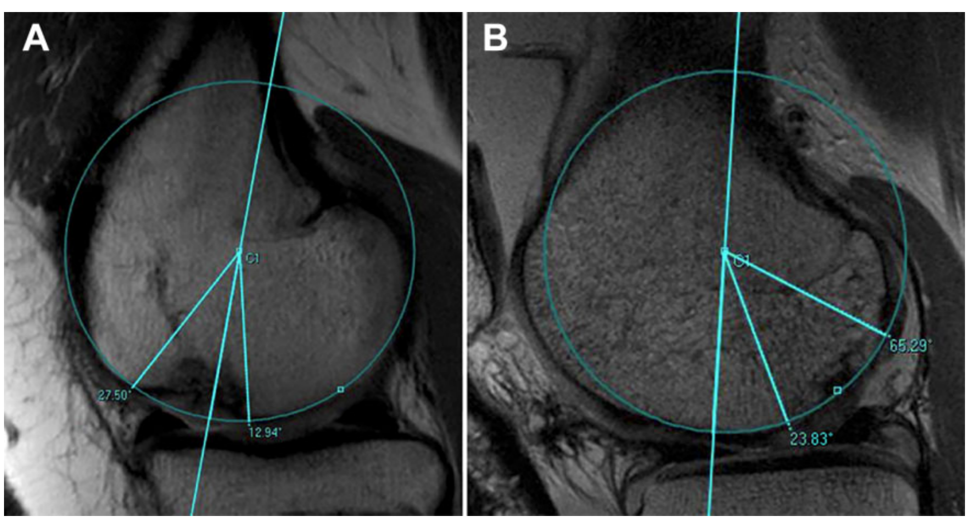

Figure 4. Sample comparison based on T1-weighted magnetic resonance imaging of angle-of-lesion incidence between (A) a patient with a body mass index (BMI) percentile in the obese range vs (B) a patient with a BMI percentile in the normal range. (A) A patient in the 97th BMI percentile with a mean angle-of-lesion incidence of −7.28° (anterior to the reference line). (B) A patient in the 45th BMI percentile with a mean angle-of-lesion incidence of 44.6° (posterior to the reference line).

described an association of obesity with genu valgum alignment in static and dynamic measures. A kinematic gait study in 40 pediatric participants suggested that patients with obesity function primarily in a genu valgum position as compared with a control group of patients with normal BMI.[20] Genu valgum should theoretically be protective of the medial compartment. Though altered loading mechanics may partially explain the association of medial femoral condyle lesions and higher BMI reported in our series, OCD development is multifactorial, and further investigation is needed to determine the overall role of loading forces and alignment.

Contrary to our hypothesis, we found that a higher BMI percentile was associated with femoral condylar lesions that were located more anteriorly than posteriorly. Our hypothesis was based on the results of a biomechanical study of kinematic data from 22 participants, which showed that obese patients spent more time in knee flexion while walking on an incline than nonobese patients.[22] However, we found that higher BMI was associated with more anterior lesions. This may reflect a preference for repetitive loading of the knee in a more extended position in patients with high BMI because they spend more time in the stance phase. If so, forces on the anterior regions of the condyles in patients with higher BMI may be larger during weight acceptance and the stance phase. In a study using 3-dimensional kinematics and kinetics to compare overweight patients with control patients during normal gait, the overweight group walked with significantly lower peak knee flexion during early stance.[6] This finding seems to contradict the increased time in knee flexion seen in these patients[22]; however, the degree of knee flexion and the length of time spent at certain degrees of flexion may have different effects on the articular surface. Further investigation into the biomechanical factors that affect the laterality and severity of lesions of the femoral condyles is needed to determine their association with BMI.

Our study was limited by its retrospective design. Specifically, a large portion of the study population was excluded because it lacked BMI data measured within a relevant time frame. This exclusion reduced our statistical power. Heterogeneity in types of imaging existed. Rather than using full-length sagittal images, we used measurements obtained from the best radiographic or magnetic resonance images available. We were unable to address mechanical axis deviation because we lacked full-length coronal imaging. Our study is also limited by the small sample size, which precluded stratification of patients by BMI percentile blocks, such as the 0 to 20th and 21st to 40th percentiles. Instead, we used cumulative percentages to allow analysis across smaller BMI percentile blocks. Furthermore, some statistical significance was lost after applying a Bonferroni correction, which inherently overcorrects type I errors and has the potential to produce type II errors; this effect is amplified in our small sample size. These limitations could be addressed with a larger, prospective study using standard full-length sagittal and coronal imaging.

CONCLUSION

To our knowledge, this is the first study to show an association in adolescents between BMI percentile and the severity and location of femoral condylar OCD lesions at presentation. These results have important implications for the prevention and early detection of OCD in adolescents, and they suggest a need for biomechanical and population-based studies of the relationship between BMI and OCD of the femoral condyles.

ACKNOWLEDGMENT

For their editorial assistance, the authors thank Jenni Weems, MS, Kerry Kennedy, BA, and Rachel Box, MS, in the Editorial Services group of The Johns Hopkins Department of Orthopaedic Surgery.

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