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The association between measures of trochlear morphology and structural features of patellofemoral joint osteoarthritis on MRI: The MOST Study

J.J. Stefanik¹, F.W. Roemer^{1,2}, A.C. Zumwalt¹, Y. Zhu¹, K.D. Gross^{1,3}, J.A. Lynch⁴, L.A. Frey-Law⁵, C.E. Lewis⁶, A. Guermazi¹, C.M. Powers⁷, and D.T. Felson¹

¹Boston University School of Medicine, Boston, Massachusetts

²Department of Radiology, Klinikum Augsburg, Augsburg, Germany

³Massachusetts General Hospital Institute for Health Professions, Boston, Massachusetts

⁴University of California, San Francisco, CA

⁵University of Iowa, Iowa City, IA

⁶University of Alabama, Birmingham, AL

⁷University of Southern California, Los Angeles, CA

Abstract

The sulcus angle has been widely used in the literature as a measure of trochlear morphology. Recently, lateral trochlear inclination and trochlear angle have been reported as alternatives. The purpose of this study was to determine the association between measures of trochlear morphology and patellofemoral joint (PFJ) cartilage damage and bone marrow lesions (BMLs). 907 knees were selected from the Multicenter Osteoarthritis Study, a cohort study of persons aged 50–79 years with or at risk for knee OA. Trochlear morphology was measured using lateral trochlear inclination, trochlear angle, and sulcus angle on axial MRI images; cartilage damage and BMLs were graded on MRI. We determined the association between quartiles of each trochlear morphology level with the presence or absence of cartilage damage and BMLs in the PFJ using logistic regression. The strongest associations were seen with lateral trochlear inclination and lateral PFJ cartilage damage and BMLs, with knees in the lowest quartile (flattened lateral trochlea) having more than two times the odds of lateral cartilage damage and BMLs compared to those in the highest quartile ($p < 0.0001$). Lateral trochlear inclination may be the best method for assessment of trochlear morphology as it was strongly associated with structural damage in the PFJ.

Keywords

trochlea; patellofemoral; osteoarthritis

Introduction

Osteoarthritis (OA) commonly occurs in the patellofemoral joint (PFJ) (1–4) and knee pain in subjects with knee OA may be emanating from the PFJ rather than the tibiofemoral joint

(TFJ) (1, 2, 5, 6). Despite this, research into risk factors and mechanisms for PFJ OA is limited compared to that of the TFJ. The PFJ is formed by the articulation between the patella and the anterior femur (trochlea). The concave trochlea has medial and lateral facets that articulate with the medial and lateral facets of the articular surface of the patella. In some instances, anatomical variants are observed with trochlear shape being more flattened than normal, a condition known as trochlear dysplasia. In these instances the patella can become unstable and is at risk for lateral dislocation and subluxation (7).

The morphology of the trochlea can be assessed in many different ways. A common description in the literature is the sulcus angle, the angle formed by the intersection of the medial and lateral trochlear facets in the transverse plane (see Methods and Figure 1). A recent study of risk factors for structural features of PFJ OA on MRI found that higher sulcus angles, representing a flattened and shallow trochlea, were associated with lateral and medial cartilage loss and lateral BMLs (8). However, an inherent flaw in the measure of the sulcus angle is that the angle will be similar in one knee that has a flattened medial facet and normal lateral facet and another that has a flattened lateral facet and normal medial facet. More recently, other measures of trochlear shape that have been reported in the literature have included lateral trochlear inclination and trochlear angle (9-11). Using a line along the posterior femoral condyles as a reference, the former is the angle between the lateral trochlear facet and this line and the latter is the angle between a line along the most anterior margin of the medial and lateral trochlear facets and this line. The use of the line along the posterior femoral condyles as a horizontal reference allows for a better measure of the orientation of the lateral trochlear facet than does the sulcus angle. The mean lateral trochlear inclination angle has been shown in one study to be lower (flattened trochlea) in knees with PFJ cartilage damage on MRI (9). However, in that study there was no distinction between cartilage damage in the medial or lateral PFJ and comparisons were based on small numbers of knees and may not be robust.

The purpose of this study was to examine the association between trochlear morphology and PFJ (medial and lateral) cartilage damage and BMLs, and to determine which measure of trochlear morphology independently predicts structural damage. We hypothesized that trochleae that are flattened would have greater structural damage compared with those lateral trochlear facets that are not flattened and that lateral trochlear inclination will be the best predictor of structural damage.

Methods

Study Population

The Multicenter Osteoarthritis (MOST) Study is a prospective cohort study of 3,026 individuals, aged 50 to 79 years, who either have or are at high risk of knee OA at baseline. Subjects were recruited from two communities in the United States: Birmingham, Alabama and Iowa City, Iowa. Details of the study population have been published elsewhere (10). Approximately 5000 knees underwent MRI during the initial study visit and of these 1800 were read for structural abnormalities. From these 1800 knees, we used a random sample of 907 that we selected for a previous study (11). The institutional review boards at the University of Iowa, University of Alabama, Birmingham, University of California, San Francisco, and Boston University School of Medicine approved the study protocol.

Trochlear morphology assessment (Figure 1)

Trochlear morphology was assessed using lateral trochlear inclination, medial trochlear inclination, trochlear angle, and sulcus angle. All were measured on the axial MRI slice where the posterior femoral condyles were largest (i.e. the slice above and below

demonstrated a smaller amount of the posterior femoral condyle). First, the posterior condylar line was drawn along the most posterior surface of the femoral condyles. Lateral and medial trochlear inclination was measured by the angle between the posterior condylar line and a line drawn along the surface of the lateral and medial trochlear facets, respectively. The trochlear angle was the angle between the posterior condylar line and a line drawn along the most anterior margins of the medial and lateral trochlear facets. Trochlear angles are higher when the lateral facet projects further anterior than the medial and lower when the medial facet projects further anterior than the lateral (a negative angle occurs when the medial facets projects further anterior than the lateral). Sulcus angle was the angle between the medial and lateral trochlear facets. All measurements were made using Osirix digital software (Version 3.2.2).

Outcome assessment

A 1.0 Tesla extremity MRI system (OrthOne™, ONI Medical Systems Wilmington, MA) was used with a phased array knee coil to acquire axial and sagittal MRIs (proton density weighted fast spin echo fat suppressed) and coronal short tau inversion recovery (STIR) sequences of all eligible knees at the baseline exam visit. Two musculoskeletal radiologists (FWR, AG) used the Whole-Organ Magnetic Resonance Imaging Score (WORMS) to assess medial and lateral patellar and trochlear facet cartilage damage (12). The cartilage scale ranges from 0-6 (Figure 2), where 0=normal cartilage morphology; 1=normal thickness but increased signal on proton density-weighted fat-suppressed images; 2.0=a single partial thickness focal defect <1 cm in greatest width; 2.5=a single full thickness focal defect <1 cm in greatest width; 3=multiple areas of partial-thickness (Grade 2.0) defects intermixed with areas of normal thickness, or a Grade 2.0 defect wider than 1 cm but <75% of the region; 4=diffuse (≥75% of the region) partial-thickness loss; 5=multiple areas of full thickness loss (grade 2.5) or a grade 2.5 lesion wider than 1 cm but <75% of the region; 6=diffuse (≥75% of the region) full-thickness loss. BMLs were also assessed using the WORMS method in the subchondral bone of the patella and trochlea in the medial and lateral compartments of the PFJ. The BML scores range from 0-3 (Figure 3), where 0=normal; 1=small, <25% of region; 2=medium, 25-50% of region; 3=large, >50% of region.

Reliability assessment

All measurements of trochlear morphology were repeated by the primary reader (JS) and a second reader (AZ) in 10% of all knees to determine inter and intra-rater reliability. Inter-rater and intra-rater ICCs for all measurements were ≥0.80 and ≥0.90, respectively. Inter-reader weighted kappa values for WORMS scores ranged from 0.62-0.78.

Statistical analysis

We first categorized the measures of trochlear morphology into quartiles to determine the relationship between multiple levels of the predictors and outcomes. Both patellar and trochlear subregions were included in analyses for the medial and lateral PFJ outcomes (4 observations per knee) and we dichotomized cartilage damage (≥2) and BMLs (≥1) into presence or absence of pathology. Cartilage grades 0 and 1 were considered no damage because grade 1 represents a change in signal but no change in thickness. To determine the association between measures of trochlear morphology and cartilage damage and BMLs in the PFJ we used logistic regression with generalized estimating equations to account for the correlation between WORMS scores for patellar and trochlear subregions from the same knee. All analyses were adjusted for age, sex, and body mass index (BMI). We also tested for a linear trend by using the predictors as continuous variables in all models. To determine which measure of trochlear morphology was the best independent predictor of structural damage, we first performed simple correlations among the three measures of trochlear

morphology. If there was a weak linear association ($r < 0.3$) between the variables we would include multiple trochlear morphology variables in the same model. Statistical analyses were performed using SAS software (SAS Institute Inc, Cary, NC, USA, version 9.1).

Results

Of the 907 knees selected for study, 26 were not included in the analysis due to missing measurements of one or more variables. This occurred due to either poor image quality or severe osteoarthritis such that bony landmarks could not be identified. Of the remaining 881 knees, 63% were from female subjects and the mean age, BMI, lateral trochlear inclination, trochlear, and sulcus angles were 63 years, 30 kg/m², 25.0, and 3.0 and 130.9 degrees, respectively (Table 1). Overall, lateral PFJ cartilage damage and BMLs occurred in 36% and 22% of the patellar or trochlear regions, respectively; medial PFJ cartilage damage and BMLs occurred in 48% and 19% of the patellar or trochlear regions, respectively (Table 2).

Tables 3-5 present the results for the associations between each trochlear morphology variable and cartilage damage and BMLs in the PFJ. There was no association between medial trochlear inclination and any of our outcomes. The strongest associations were seen with lateral trochlear inclination. In the lateral PFJ, knees with low lateral trochlear inclination had 2.6 (95% CI 1.9, 3.7; $p < 0.0001$) and 2.3 (95% CI 1.5, 3.3; $p < 0.0001$) times the odds of cartilage damage and BMLs compared to those with high lateral trochlear inclination. With decreasing lateral trochlear inclination, there was an increase in structural damage (p for trend < 0.0001). In the medial PFJ, knees with low lateral trochlear inclination had 1.6 (95% CI 1.2, 2.1; $p = 0.003$) times the odds of cartilage damage compared to those with high lateral trochlear inclination. For the trochlear angle, knees with low trochlear angles had 2.0 (95% CI 1.2, 3.5; $p < 0.0001$) times the odds of cartilage damage in the lateral PFJ compared to those with high trochlear angles. With decreasing trochlear angles, odds of cartilage damage increased, p for trend 0.0002. The weakest associations were seen between the sulcus angle and structural damage. In the lateral PFJ knees with high sulcus angles had 1.5 (95% CI 1.1, 2.1; $p = 0.01$) and 1.6 (95% CI 1.1, 2.3; $p = 0.02$) times the odds of cartilage damage and BMLs, respectively.

Trochlear angle was weakly correlated with sulcus angle and lateral trochlear inclination, $r = 0.22$ and 0.27 , respectively. Lateral trochlear inclination was strongly correlated with sulcus angle, $r = -0.75$. Because of the weak correlation between trochlear angle and sulcus angle, we included trochlear angle quartiles in the models with lateral trochlear inclination quartiles and sulcus angle quartiles as the primary predictor. The results of the models with multiple trochlear morphology variables were similar to the main results of models with each variable alone.

Discussion

Our results demonstrate a strong association between trochlear morphology, specifically lateral trochlear inclination, and PFJ structural damage. Knees with low lateral trochlear inclination (flattened lateral trochlea) had more than two times the odds of lateral PFJ cartilage damage and BMLs compared with knees with high lateral trochlear inclination. These results support the hypothesis that those knees with flattened lateral trochlea are at increased risk for structural damage in the PFJ. As the knee begins to flex from an extended position, the patella will glide inferiorly and enter the trochlear groove. When the lateral facet is flattened, the patella will be more likely to be displaced laterally due to the lateral force vector acting on the patella as a result of the angle of pull of the quadriceps muscle (13). Thus, knees with a trochlea that lacks a lateral “barrier” may be subject to increased shear forces between the patella and trochlea leading to cartilage damage and BMLs in the

PFJ. We found no association between medial trochlear inclination and structural damage in either the lateral or medial PFJ. These results suggest that the inclination of the medial trochlear facet may not be as important in the stability of the PFJ as the lateral trochlear facet.

Previous studies have investigated the association between trochlear morphology and PFJ OA (8, 14-17). To our knowledge no other study has investigated this question with as much detail in the measurement of our outcomes (cartilage damage and BMLs). Ali et al found the mean lateral trochlear inclination in knees from subjects > 40 years old with no and severe cartilage damage to be 22.8 and 14.7 degrees, $p=0.007$ (9). However, they did not define cartilage damage in specific anatomic regions of the PFJ (i.e. medial vs. lateral).

Additionally, they found no differences in the mean sulcus angle between the groups. Our results also demonstrate a strong association between lower lateral trochlear inclination and lateral PFJ cartilage damage and BMLs, and also with medial PFJ cartilage damage. We also found an association between higher sulcus and cartilage damage and BMLs in lateral PFJ, albeit not as strong as lateral trochlear inclination. Trochlear angle, the third measure of trochlear morphology, also demonstrated a strong association with lateral PFJ cartilage damage (Table 4).

Both lateral trochlear inclination and trochlear angle use the posterior condylar line as a reference line, whereas the sulcus angle measures the angle between the medial and lateral trochlear facets. The sulcus angle may be similar in one knee that has a flattened medial facet and normal lateral facet and another that has a flattened lateral facet and normal medial facet. Despite finding an association between all three measures of trochlear morphology and structural damage, lateral trochlear inclination demonstrated the strongest association, as the results were similar when also accounting for the effect of the trochlear angle. Therefore, this variable should be included in future studies investigating PFJ pathology and can be easily measured to help identify patients at risk for PFJ OA.

Lateral trochlear inclination was also associated with medial PFJ cartilage damage, although not as strongly as lateral PFJ cartilage damage or BMLs. The mechanism for this damage may be different than for that of lateral PFJ damage. As the knee extends in knees with low lateral trochlear inclination, the patella is likely to be displaced laterally due to the shallow proximal trochlea (18). As the knee begins to flex again, the patella, starting from a lateral position, would need to re-engage the trochlea and glide medially to center itself in the trochlea. When this occurs, there is potential that the patella may compress the medial PFJ while it is reengaging in the trochlea. Additionally, studies have demonstrated that the patella does displace medially in the initial degrees of flexion (19-22). However, it is unknown if this medial displacement increases forces and stress in the medial PFJ.

We recognize limitations in this current study. First, using a cross-sectional design we cannot infer causality from our results. However, reverse causation is unlikely as the shape of the femoral trochlea likely does not change over time and structural damage in the PFJ would not cause changes in trochlear morphology. Second, the slice chosen to measure trochlear morphology could affect our results. We chose the slice where the posterior femoral condyles projected most posteriorly, which corresponds to the proximal trochlea and allows for visualization of both the medial and lateral trochlear facets on one slice. Finally, we acknowledge that measures of trochlear morphology can also be assessed from lateral or tangential (skyline) radiographs. However, a tangential radiograph is difficult to reproduce consistently (23) and also only allows for visualization at one level of the trochlea. Using MRI we were able to focus on the proximal trochlea and also assess differences in the inclination of the lateral and medial trochlea, separately. It is also

unknown if MRI measures of trochlear morphology correlate better with clinical findings (i.e. pain, function, etc.) than radiographic measures.

In summary, low lateral trochlear inclination was strongly associated with lateral PFJ cartilage damage and BMLs, and with medial PFJ cartilage damage. Additionally, the sulcus angle, which is most commonly reported in the literature, was not as strongly associated with structural damage as lateral trochlear inclination. Lateral trochlear inclination is easily measured from MRI and can be used to identify individuals at risk for knee OA.

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Figure 1. Measurement of trochlear morphology

All measurements were made on the axial MRI slice where femoral condyles are most posterior. Sulcus angle (SA) is the angle between the medial and lateral trochlear facets (Panel A). For lateral trochlear inclination (LTI), medial trochlear inclination (MTI), and trochlear angle (TA) measurement, a posterior condylar line is drawn along posterior femoral condyles. Lateral and medial trochlear inclination is the angle between the posterior condylar line and a line along the lateral and medial facets, respectively (Panel B). Trochlear angle is the angle between the posterior condylar line and a line passing along the most anterior margin of the medial and lateral trochlear facets (Panel C).

A

B

C

D

E

F

G

Figure 2. Assessment of cartilage damage using the WORMS method

A. Axial proton-density weighted fat suppressed image. Grade 1 cartilage damage is shown in the medial and lateral patellar facets (arrows) representing intrachondral hyperintensity signal of unknown relevance.

B. Axial proton-density weighted fat suppressed image. A small grade 2 cartilage lesion representing a tiny superficial defect is depicted in the lateral facet (arrow).

C. Axial proton-density weighted fat suppressed image. A small full thickness focal defect (arrow) is depicted in the lateral patellar facet (=grade 2.5 lesion).

D. Axial proton-density weighted fat suppressed image. Diffuse superficial cartilage damage of less than 75% of subregion (=grade 3 cartilage damage) is observed in the medial (arrowheads) and lateral patellar facets (arrows).

E. Axial proton-density weighted fat suppressed image. Diffuse superficial damage of more than 75% of subregion (= grade 4 cartilage damage) is shown in the lateral patellar facet (arrowheads). Note also several subchondral BMLs representing a grade 3 lesion in the adjacent subchondral bone.

F. Axial proton-density weighted fat suppressed image. Diffuse full thickness cartilage loss (less than 75%) is seen in the medial patellar facet representing grade 5 cartilage damage (arrows).

G. Axial proton-density weighted fat suppressed image. Diffuse full thickness cartilage damage >75% (=grade 6) is depicted in the lateral patellar facet (arrows)). Note adjacent BMLs (arrowheads).

A

B

C

Figure 3. Assessment of bone marrow lesions (BMLs) using the WORMS method

A. Axial proton-density weighted fat suppressed image. Small (grade 1) subchondral BML is observed in the lateral patellar facet (arrow).

B. Axial proton-density weighted fat suppressed image. A grade 2 BML is seen in the medial patellar facet (arrowheads).

C. Axial proton-density weighted fat suppressed image. A large grade 3 BML is depicted in the lateral patellar facet (arrowheads). Further note grade 2 BML in the communicating lateral femoral trochlea (arrow).

Table 1

Descriptive statistics (n=881 knees)*

Female (%)	63%
Age, years	62.5 (8.0)
Range	(50-70)
BMI, kg/m ²	30.0 (4.8)
Range	(18.0-29.0)
Lateral trochlear inclination, degrees	25.0 (5.2)
Range	(4.5-5.2)
Medial trochlear inclination, degrees	24.4 (6.1)
Range	(-0.4-44.1)
Trochlear angle, degrees	3.0 (3.2)
Range	(-9.7-3.2)
Sulcus angle, degrees	130.9 (8.9)
Range	(99.1-159.5)

* Values are mean $\pm$ SD unless otherwise indicated

Table 2

Frequency of structural outcomes *

<u>Lateral PFJ</u>	
Cartilage damage	642/1760 (36%)
BMLs	379/1761 (22%)
<u>Medial PFJ</u>	
Cartilage damage	848/1760 (48%)
BMLs	343/1761 (19%)

* Outcomes combine the scores from the patella and trochlea, as described in methods. Missing values for 2 regions for lateral and medial cartilage damage and 1 region for lateral and medial BMLs.

Table 3

The association between quartiles of lateral trochlear inclination (LTI) and patellofemoral joint (PFI) cartilage damage and bone marrow lesions.

	Quartile 1 (High)	Quartile 2	Quartile 3	Quartile 4 (Low)	p for trend
LTI Range	>28.11	24.92-28.11	21.70-24.91	<21.7	
# of knees	220	221	220	220	
<i>Lateral PFI</i>					
Cartilage Damage					
WORMS ≥ 2 n/N	109/439	159/441	170/440	204/440	
(%)	(25)	(36)	(39)	(46)	
Adjusted OR *	1.0	1.7	1.9	2.6	<0.0001
(95% CI)	(reference)	(1.2, 2.4)	(1.4, 2.7)	(1.9, 3.7)	
Bone Marrow Lesions					
WORMS ≥ 1 n/N	70/439	79/442	99/440	131/440	
(%)	(16)	(18)	(23)	(30)	
Adjusted OR *	1.0	1.1	1.5	2.3	<0.0001
(95% CI)	(reference)	(0.8, 1.7)	(1.0, 2.3)	(1.5, 3.3)	
<i>Medial PFI</i>					
Cartilage Damage					
WORMS ≥ 2 n/N	182/439	215/441	224/440	227/440	
(%)	(41)	(49)	(51)	(52)	
Adjusted OR *	1.0	1.3	1.5	1.6	0.004
(95% CI)	(reference)	(1.0, 1.8)	(1.1, 2.0)	(1.2, 2.1)	
Bone Marrow Lesions					
WORMS ≥ 1 n/N	81/439	98/442	90/440	74/440	
(%)	(18)	(22)	(21)	(17)	
Adjusted OR *	1.0	1.3	1.1	0.9	0.39
(95% CI)	(reference)	(0.9, 1.8)	(0.8, 1.6)	(0.6, 1.3)	

* OR=odds ratio, adjusted for age, sex, and BMI

Table 4

The association between quartiles of trochlear angle (TA) and patellofemoral joint (PFJ) cartilage damage and bone marrow lesions.

	Quartile 1 (High)	Quartile 2	Quartile 3	Quartile 4 (Low)	p for trend
TA Range	<4.96	2.96-4.94	0.87-2.95	<0.8	
# of knees	220	221	220	220	
<i>Lateral PFJ</i>					
Cartilage Damage					
WORMS ≥ 2 n/N	130/440	152/439	161/442	199/439	
(%)	(30)	(35)	(36)	(45)	
Adjusted OR *	1.0	1.3	1.4	2.0	0.0002
(95% CI)	(reference)	(0.5, 1.6)	(0.9, 2.5)	(1.2, 3.5)	
Bone Marrow Lesions					
WORMS ≥ 1 n/N	77/440	94/439	100/442	108/440	
(%)	(18)	(21)	(23)	(25)	
Adjusted OR *	1.0	1.3	1.4	1.5	0.01
(95% CI)	(reference)	(0.9, 1.9)	(1.0, 2.0)	(1.1, 2.2)	
<i>Medial PFJ</i>					
Cartilage Damage					
WORMS ≥ 2 n/N	206/440	219/439	200/442	223/439	
(%)	(47)	(50)	(45)	(51)	
Adjusted OR *	1.0	1.2	1.0	1.2	0.37
(95% CI)	(reference)	(0.9, 1.6)	(0.7, 1.3)	(0.9, 1.6)	
Bone Marrow Lesions					
WORMS ≥ 1 n/N	87/440	95/439	87/442	74/440	0.08
(%)	(20)	(22)	(20)	(17)	
Adjusted OR *	1.0	1.1	1.0	0.8	
(95% CI)	(reference)	(0.8, 1.6)	(0.7, 1.4)	(0.6, 1.1)	

* OR=odds ratio, adjusted for age, sex, and BMI

Table 5

The association between quartiles of sulcus angle (SA) and patellofemoral joint (PFJ) cartilage damage and bone marrow lesions.

	Quartile 1 (Low)	Quartile 2	Quartile 3	Quartile 4 (High)	p for trend
SA Range	<125.14	125.14-131.12	131.13-136.54	>136.54	
# of knees	220	221	220	220	
<i>Lateral PFJ</i>					
Cartilage Damage					
WORMS ≥ 1 n/N	148/438	152/440	153/442	189/440	
(%)	(34)	(35)	(35)	(43)	
Adjusted OR *	1.0	1.0	1.1	1.5	0.004
(95% CI)	(reference)	(0.7, 1.4)	(0.8, 1.5)	(1.1, 2.1)	
Bone Marrow Lesions					
WORMS ≥ 1 n/N	86/439	85/440	88/442	120/440	
(%)	(20)	(19)	(20)	(27)	
Adjusted OR *	1.0	1.0	1.0	1.6	0.007
(95% CI)	(reference)	(0.7, 1.4)	(0.7, 1.5)	(1.1, 2.3)	
<i>Medial PFJ</i>					
Cartilage Damage					
WORMS ≥ 1 n/N	204/438	212/440	203/442	229/440	
(%)	(47)	(48)	(46)	(52)	
Adjusted OR *	1.0	1.1	1.0	1.3	0.08
(95% CI)	(reference)	(0.8, 1.4)	(0.7, 1.3)	(1.0, 1.7)	
Bone Marrow Lesions					
WORMS ≥ 1 n/N	82/439	90/440	85/442	86/440	
(%)	(19)	(20)	(19)	(20)	
Adjusted OR *	1.0	1.1	1.0	1.1	0.84
(95% CI)	(reference)	(0.8, 1.6)	(0.7, 1.4)	(0.7, 1.5)	

* OR=odds ratio, adjusted for age, sex, and BMI