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Meniscal subluxation: association with osteoarthritis and joint space narrowing

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Summary

Objective: Since complete meniscectomy leads to knee OA, we investigated the potential links among meniscal subluxation, joint space narrowing and symptomatic OA.

Materials and methods: 233 cases with symptomatic knee OA and 58 asymptomatic controls underwent radiography and MR imaging of the knee. Joint space narrowing was measured on weight-bearing PA fluoroscopy-positioned radiographs. The amount of medial or lateral meniscal subluxation was measured on coronal MR images. The prevalence and severity of meniscal subluxation was compared in cases and controls. We evaluated the correlation of the degree of meniscal subluxation with joint space narrowing, Kellgren and Lawrence grade, and two major risk factors for the development of OA, age and weight.

Results: Cases had more medial and lateral subluxation than controls. Mean medial meniscal subluxation was 5.1 mm in cases and 2.8 mm in controls (P=0.001). Modest degrees of meniscal subluxation were common in both cases and controls: 81% of cases and 64% of controls had ≥3 mm of subluxation; age and gender adjusted (P=0.006). Severe degrees of subluxation were almost unique to OA cases (e.g. prevalence of ≥7 mm, 35% cases vs. 7% controls, P<0.001). Among controls, severe degrees of subluxation were present only in those with radiographic joint space narrowing (defined as ≥grade 1 narrowing on a 0–3 scale). In cases, there was a strong correlation between the degree of medial meniscal subluxation and the severity of medial joint space narrowing (r=0.56, P=0.0001). Similar results were present in the lateral compartment. Meniscal subluxation did not correlate with age or weight.

Conclusion: Meniscal subluxation is highly associated with symptomatic knee OA. In subjects with osteoarthritis, increasing meniscal subluxation on MR correlates with the severity of joint space narrowing. © 1999 OsteoArthritis Research Society International

Key words: Knee osteoarthritis, Meniscus.

Introduction

Symptomatic osteoarthritis (OA) occurs in 11% of persons aged 65 and over and approximately 6% of the overall U.S. adult population.[1] It accounts for most total knee replacements and for as much or more lower extremity disability as any disease.

In the knee, the menisci function as buffers by distributing axial load and protecting the adjacent articular cartilage.[2] They also stabilize the knee. In both clinical practice and experimental models, complete meniscectomy has been shown to predispose to premature osteoarthritis.[3,4] We hypothesized that significant meniscal subluxation, displacement away from or uncovering the tibial articular cartilage, would occur more often in subjects with knee OA than controls either because it caused the OA or because laxity of supporting meniscal structures associated with OA predisposes to meniscal subluxation. In either case significant meniscal subluxation may simulate a condition similar to complete meniscectomy.

Joint space narrowing is a primary radiographic feature of OA. Hyaline cartilage erosion and loss are characteristic pathologic findings in OA. Arthroscopic and arthrographic studies of knee OA have suggested a moderate correlation between radiographic joint space narrowing and loss of hyaline articular cartilage.[5,6] While hyaline articular cartilage loss accounts for some joint space narrowing, menisci comprise some of the space between femur and tibia, especially along the periphery of the joint. Meniscal removal or displacement could also account for and contribute to joint space narrowing.

Meniscal findings in older asymptomatic subjects have not been well studied. Recent reports have documented some association of meniscal protrusion with radiographic findings in osteoarthritis such as osteophyte formation, anterior cruciate ligament tear or joint effusion.[7,8] However, these studies have not evaluated the relationship of meniscal subluxation to the presence of osteoarthritis nor assessed the degree of subluxation and its association with joint space narrowing, a distinctive feature of OA. The link between joint space narrowing and meniscal subluxation is a matter of considerable importance because narrowing, which is commonly thought to represent hyaline articular cartilage loss, has been and continues to be used as the primary outcome measure for knee OA in clinical practice and investigative trials.[9]

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This study evaluated the prevalence of meniscal subluxation in symptomatic OA cases versus asymptomatic controls. In symptomatic OA cases, we tested the correlation of meniscal subluxation measured on MRI with joint space narrowing measured on weight bearing knee radiographs. In addition, we evaluated the correlation of meniscal subluxation with age and weight, two of the major risk factors for the development of OA. The focus of this investigation was subluxation in those with symptomatic OA (our cases), with the recognition that controls, while asymptomatic, may, like many older persons, have evidence of radiographic OA.

Materials and methods

PATIENT SELECTION

The minimum age for entry into the study was 40 years for men and 50 years for women. The minimum entry age for women was older in order to lessen the chance of inadvertently obtaining radiographs on pregnant women. Male subjects were drawn from the longitudinal Veterans Health Study, a cohort study of 2425 men receiving care at regional area medical centers, designed to evaluate the relationship between chronic diseases and health outcomes.[10] Female subjects were drawn from a similar study, the Women's Health Project (N=800) that was designed to describe the health status of women veterans using ambulatory services. The human studies committee and the institutional review board approved protocols for both the parent studies and the knee osteoarthritis sub-study. Informed consent was obtained from all subjects.

During assessment in these parent studies, subjects were surveyed about knee symptoms. They were asked two questions: 'Do you have pain, aching or stiffness in one or both knees on most days?', and 'Has a doctor ever told you that you have knee arthritis?'. In a follow-up interview, those answering positively to both questions were asked about other types of arthritis that could cause knee symptoms. If no other forms of arthritis were identified in the interview or from review of the individual's medical record, then the individual was eligible for recruitment as a case.

Controls were recruited from among those who answered in the negative to both of the above screening questions and these persons were characterized as controls irrespective of their radiographic findings.

RADIOGRAPHIC EVALUATION

In cases and controls, weight-bearing PA using the protocol of Buckland-Wright,[11] weight-bearing skyline and weight-bearing lateral radiographs were obtained.[12] For the PA view, the knee was positioned and radiographed under fluoroscopy so that the anterior and posterior medial tibial plateaus were superimposed in order to optimize the measurement of joint space narrowing. This technique improves the accuracy of joint space narrowing measurements. Radiographs were read for the presence of definite osteophytes and other features by one radiologist (DRG) using an atlas. If a definite osteophyte was present in a symptomatic knee on any one of three views, the subject was characterized as an OA case (this includes the patella). This definition meets American College of Rheumatology criteria [13] for knee OA. Symptomatic individuals without a radiographic osteophyte were excluded from this study since they met neither the criteria for knee OA nor asymptomatic control.

Radiographic joint space narrowing in each tibio-femoral compartment of each knee was evaluated using both semi-quantitative and quantitative methods. These evaluations were conducted independently of one another and the readers were blinded to case status and MRI findings. The semi-quantitative measurements, developed for the Framingham Osteoarthritis Study, used a four-point scale (0–3 where 0 was no evidence of joint space narrowing and 3 represented absent joint space).[14] We defined a knee as having joint space narrowing if there was joint space narrowing (≥1 on a 0–3 scale) in at least one tibio-femoral compartment. The intraobserver agreement for this dichotomous definition of narrowing was Kappe=0.6 (P<0.001).

In the quantitative method, joint space narrowing (technically the distance between femoral condyle and tibial plateau) was measured at three points in the medial and lateral compartments of each knee: the most peripheral site at which femur apposed tibia; the narrowest site; and the site measured to be at the center of the compartment (midpoint) using a previously developed protocol.[15] Joint space narrowing was measured between points using calipers with an electronic readout of the distance. Because magnification of images occurs with this imaging protocol, we used a fixed size ball bearing taped to the knee and adjusted for its magnification to compute joint space narrowing. Reproducibility of these readings was high (intra-observer ICC=ranged from 0.96–0.995 across medial and lateral compartment sites). The severity of osteoarthritis on the PA projection was also scored from 0–4 using the Kellgren and Lawrence scale.[16]

MRI EVALUATION

Each case underwent MRI of the more symptomatic knee. For controls the dominant knee was selected for imaging. All studies were performed on a GE Signa 1.5 Tesla MR (GE Medical Systems, Milwaukee, Wisconsin) using a phased array knee coil. A positioning device for the ankle and knee was used to ensure uniformity between patients. The MR protocol for each subject included coronal, sagittal and axial images. Coronal spin echo fat saturated proton density and T2 weighed fat saturated images (TR 2200 TE 20/80) with a slice thickness of 3 mm, a 1-mm interslice gap, 1 NEX, field of view 11–12 cm, and a matrix of 256×128 were used.

MRIs of the cases and controls were randomly mixed and the three MRI readers (DRG, SMST, RKS) were blinded to case status. Meniscal subluxation was measured to the nearest millimeter on the coronal images using a MR generated scale on each image (Fig. 1). Meniscal subluxation was defined as the greatest distance from the most peripheral aspect of the meniscus to the border of the tibia excluding any osteophyte on any one of the multiple coronal images. Inter- and intra-observer reliability of meniscal subluxation measurements was tested using a subset of the MRI exams.

The inter-observer intraclass correlation coefficient (ICC) for medial subluxation was 0.85 (P<0.0001) and for lateral subluxation was 0.76 (P<0.0001). The intra-observer ICC for medial subluxation was 0.93 (P<0.0001). There were insufficient numbers of subset cases to test for intra-observer lateral subluxation.

Weights were measured as part of the parent study evaluation and were obtained only in the study of men and

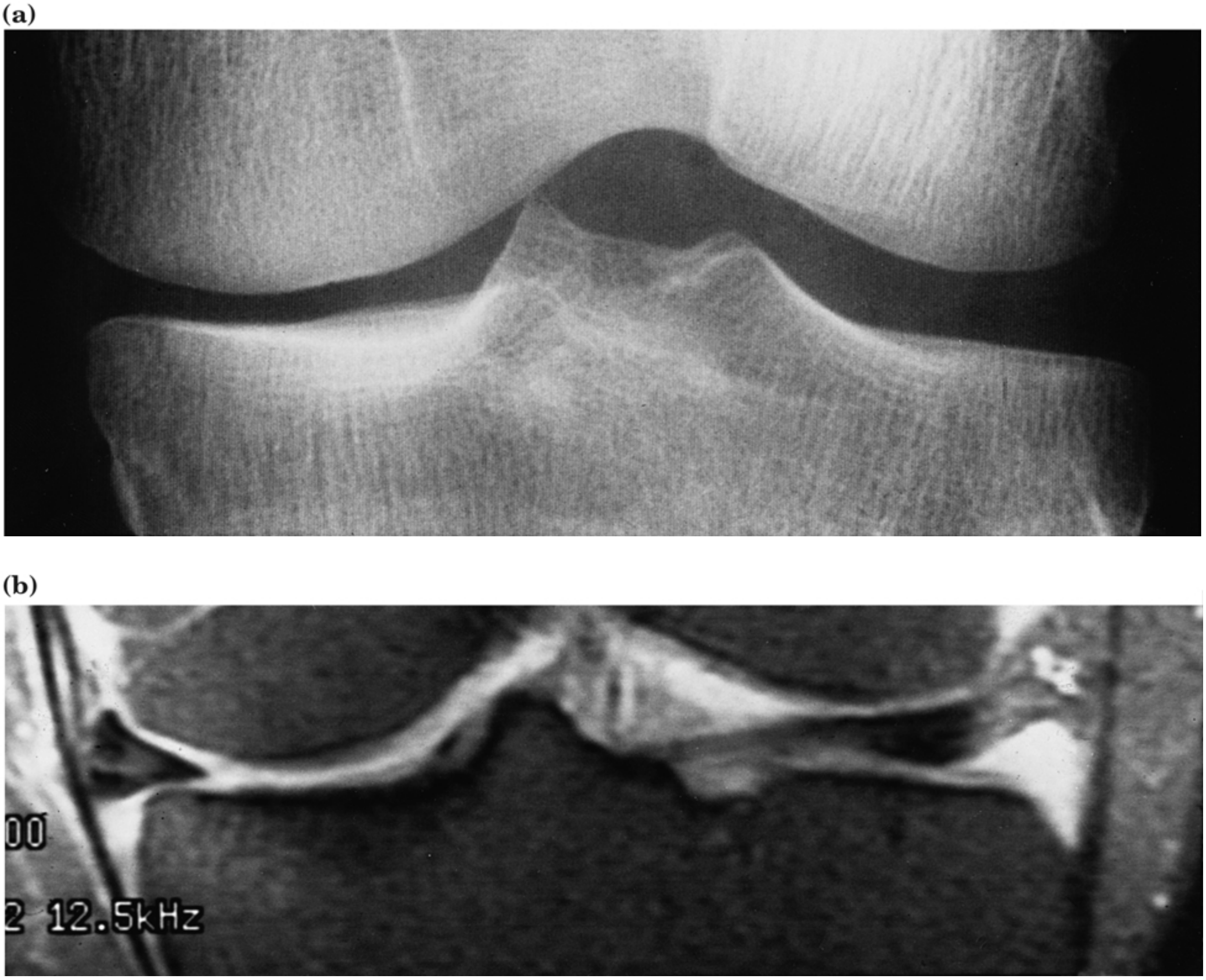

Fig. 1. (a) An AP view of the knee demonstrates grade I narrowing medially using the qualitative scale. (b) The corresponding proton density weighted fat saturation MR image demonstrates 4 mm of subluxation of the medial meniscus beyond a vertical line through the medial border of tibia. The articular cartilage is relatively well preserved.

not women. Male subjects were weighed using a balance beam scale.

Only one knee per subject was studied by MRI and thus the analyses are knee and subject specific. Analysis focused on the difference between proportions (chi square or Fisher's exact test when appropriate) and differences in continuous measures was tested using t test (e.g., subject age). *P*-values reported are two-sided. To adjust for age (and for gender or weight when appropriate) in comparing the prevalence of meniscal subluxation in cases versus controls, we used logistic regression using case status as the dependent variable. To evaluate the association between the amount of meniscal subluxation and joint space narrowing as well as risk factors for OA, we computed Pearson correlation coefficients. For some analyses evaluating controls, we separated controls with any tibiofemoral joint space narrowing (defined as a score of ≥1 on semi-quantitative scale (0–3) in either medial or lateral compartment) from those without narrowing.

With controls separated into those with and without narrowing, we created three analytic groups: cases, controls with X-ray OA and narrowing (control A), and controls without narrowing (control B). To analyse whether subluxation correlated with knee symptoms, controlling for radiographic disease, we compared the mean subluxation of cases vs. control A. To evaluate whether subluxation was associated with narrowing, we compared the degree of subluxation in controls A and B. We performed both comparisons above by carrying out a multiple regression analysis in which the log-transformed value for medial subluxation was the dependent variable and independent variables included age, gender and group (a class variable: either case, control A or control B). This permitted us to compare least squares means values for medical subluxation in the three groups.

Results

There were a total of 203 male and 31 female cases with symptomatic and radiographic knee OA from our Veteran population, which is predominantly comprised of men. There were 27 male and 30 female controls (Table I). Female cases were similar in age to female controls, while male cases were slightly older than their controls. Male cases were slightly heavier than their respective controls. All cases and 70% of controls (67% of males and 74% of females) had some evidence of radiographic OA (at least a

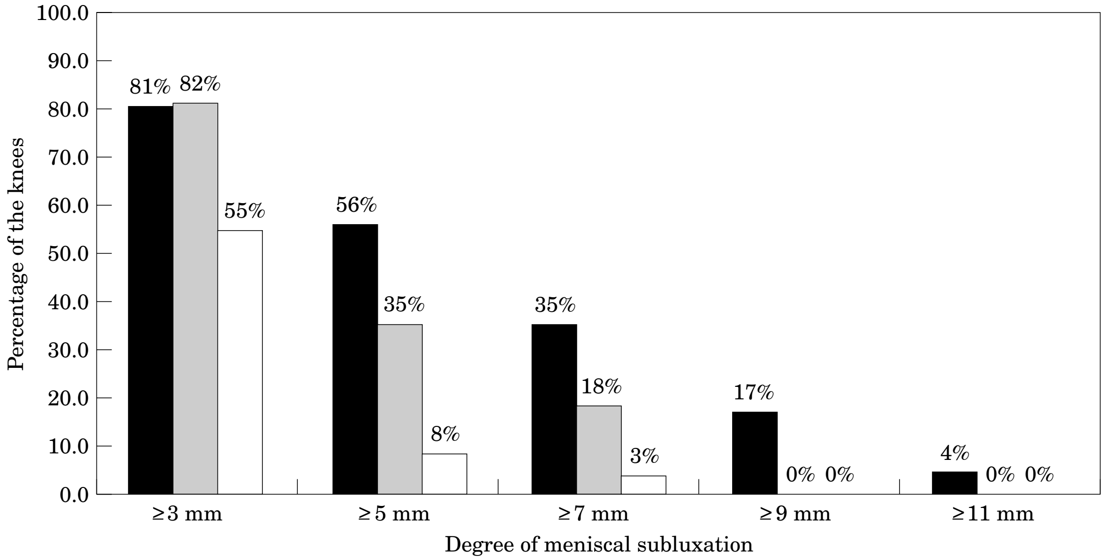

Fig. 2. Prevalence of medial subluxation in cases and controls with and without JSN, at different levels of subluxation. ■, case; ▨, Control with JSN; □, control without JSN.

Table I
Description of cases and controls

	Cases	Controls	*P*-value (Chi-square)
Men (*N*)	203	27	
Mean age (years) (±s.d.)	67 (±10)	65 (±10)	0.23
Mean weight (lbs) (±s.d.)	201 (±35)	189 (±34)	0.12
Joint space narrowing (≥1 on a 0–3 scale) (%)	130 (64%)	4 (15%)	<0.001
Women (*N*)	31	30	
Mean age (years) (±s.d.)	66 (±10)	66 (±8)	0.78
Mean weight (lbs) (±s.d.)	NA*	NA	NA
Joint space narrowing (≥1 on a 0–3 scale) (%)	26 (84%)	13 (43%)	<0.001

*Data not available for women.

small definite osteophyte) on at least one radiographic view. In both men and women, using the semi-quantitative scale, cases were more likely than controls to demonstrate any joint space narrowing (P=0.001).

The mean medial meniscal subluxation was greater in cases than controls (Table II). In men, the mean medial meniscal subluxation was 5.3 mm (±3.1) in cases and 2.9 mm (±2.2) in controls (P=0.0002), and the mean lateral meniscal subluxation was 0.62 mm (±1.8) in cases and 0.48 mm (±1.4) in controls (P=0.69). In women, the mean medial meniscal subluxation was 4.3 mm (±3.4) in cases and 2.7mm (±2.1) in controls (P=0.03), and mean lateral meniscal subluxation was 1.9 mm (±3.4) in cases and 0 mm (±0) in controls.

At every level of medial meniscal subluxation, the prevalence was significantly greater for cases than controls. Medial meniscal subluxation, defined as 3 mm or greater, was present in 81% of the cases and 64% of controls (P=0.006). Further, medial subluxation of ≥7 mm occurred in 35% of cases and 7% of controls (P<0.001). Also, at every threshold of medial subluxation, rates were higher among both male and female cases than their respective controls.

We then assessed whether the amount of meniscal subluxation differed among controls with joint space narrowing and those without joint space narrowing, and compared those rates of subluxation to those of cases. In cases and controls with and without joint space narrowing (using the semiquantitative scale score of ≥1 in at least one compartment), we found that more severe degrees of subluxation occurred almost uniquely in those with narrowing (Fig. 2). For example, in controls with no joint space narrowing, only 3/38 (8%) had meniscal subluxation of at least 5 mm. However, in controls with joint space narrowing, 6/17 (35%) had this degree of meniscal subluxation. The number of cases and controls demonstrating lateral subluxation was smaller; lateral subluxation of ≥5 mm did not occur in any controls, but occurred in 20/232 (9%) of cases.

We performed an analysis comparing the degree of medial subluxation in cases and two groups of controls (those with and without narrowing) after controling for age and gender and found the adjusted mean subluxation in cases was 1.32 mm (95% CI 1.20, 1.45) For controls with narrowing, the adjusted mean subluxation was 1.22 mm (95% CI 0.75, 1.69; P=0.68 vs. cases). For controls without narrowing, the adjusted mean subluxation was 0.64 mm (95% CI 0.34, 0.95); P=0.04 vs. controls with narrowing).

Meniscal subluxation was correlated with joint space narrowing (quantitative method) in both male and female

Table II
Mean meniscal subluxation (±s.d.) in cases vs. controls

	Cases	Controls	*P*-value*
Medial			
Men	5.3 mm (±3.1)	2.9 mm (±2.2)	0.0002
Women	4.3 mm (±3.4)	2.7 mm (±2.1)	0.033
Men and women	5.1 mm (±3.2)	2.8 mm (±2.1)	0.0001
Lateral			
Men	0.62 mm (±1.8)	0.48 mm (±1.4)	0.69
Women	1.9 mm (±3.4)	0 mm (±0)	†
Men and women	0.8 mm (±2.1)	0.23 mm (±0.96)	0.039

*Adjusted for age and when appropriate for gender and age.
†Unable to calculate *P*-value due to lack of distribution in controls.

Table III
Correlation (r values) of meniscal subluxation on MRI with joint space narrowing on X-ray

	Mid point of compartment*	*P*-value	Most peripheral site in compartment*	*P*-value	Narrowest site in compartment*	*P*-value
Medial						
Men	0.50	0.0001	0.51	0.0001	0.54	0.0001
Women	0.64	0.0002	0.57	0.0007	0.59	0.0006
All cases	0.53	0.0001	0.53	0.0001	0.55	0.0001
Lateral						
Men	0.31	0.0001	0.28	0.006	0.34	0.0001
Women	0.43	0.017	0.43	0.002	0.44	0.015
All cases	0.39	0.0001	0.40	0.0001	0.40	0.0001

*These sites are defined in Methods.

Table IV
Bivariate correlation (r value) of meniscal subluxation with other factors in knee osteoarthritis cases*

	Medial correlation coefficient	*P*-value	Lateral correlation coefficient	*P*-value
Men				
Kellgren & Lawrence Grade (0–4)	0.58	0.0001	0.20	0.005
Age (years)	0.15	0.03	0.15	0.04
Weight (lbs)	0.01	0.86	0.005	0.95
Women				
Kellgren & Lawrence Grade (0–4)	0.38	0.03	0.46	0.009
Age (years)	0.06	0.76	0.43	0.014
Weight (lbs)	N/A		N/A	
All				
Kellgren & Lawrence Grade (0–4)	0.58	0.0001	0.25	0.0001
Age (years)	0.13	0.06	0.20	0.003

*Degree of meniscal subluxation is assessed on a continuous scale.

cases. In cases the mean joint space height at the narrowest point in the medial compartment was 3.26 mm (±1.34 s.d.) In men, there was a correlation of r=0.50 to 0.54 (P=0.0001) between medial joint space narrowing on X-ray and medial meniscal subluxation on MRI (Table III). In women there was a similar correlation in the medial joint compartment (r=0.57 to 0.64 (P=0.001)). In men, correlations between lateral joint space narrowing on X-ray and lateral subluxation on MRI were lower (r=0.28 to 0.34) than in women (r=0.43 to 0.44).

In those without meniscal subluxation, joint space narrowing was very uncommon. Of the twenty controls with <3 mm of medial meniscal subluxation, only three (15%) demonstrated medial joint space narrowing (≥1 on a 0–3 scale) and of fifty-four controls with <3 mm of lateral meniscal subluxation, only three (6%) had lateral joint space narrowing. Of cases, sixteen of forty-two (38%) cases without medial meniscal subluxation (<3 mm) demonstrated medial joint space narrowing, whereas only seven of 194 (4%) cases without lateral meniscal subluxation demonstrated lateral joint space narrowing.

For male cases, there was little correlation between age and the amount of medial subluxation [r=0.15 (P=0.03)] and lateral subluxation [r=0.15 (P=0.04)] (Table IV). Similarly there was no correlation between weight and the amount of medial subluxation [r=0.01 (P=0.86)] or lateral subluxation [r=0.005 (P=0.95)]. For female cases, there was no correlation between age and the amount of medial subluxation [r=0.06 (P=0.76)] but there was a moderate correlation between age and lateral subluxation [r=0.44

($P=0.014$)]. Kellgren and Lawrence grade was moderately correlated with the degree of meniscal subluxation.

Discussion

This study demonstrates that meniscal subluxation is substantially and significantly more common in symptomatic osteoarthritis cases than asymptomatic controls. Importantly, the study also indicates that the amount of medial meniscal subluxation correlates with the degree of medial joint space narrowing in both men and women, and lateral subluxation with lateral joint space narrowing in women. In men, the correlation between lateral subluxation and lateral joint space narrowing is less strong, probably because few male cases demonstrated lateral joint space narrowing. Since joint space narrowing is an essential component of the Kellgren and Lawrence scale, it is not surprising that meniscal subluxation also correlates well with Kellgren and Lawrence grade.

Because our study was cross-sectional, etiologic inferences can not be drawn. Either subluxation contributes to the development of joint space narrowing and knee osteoarthritis, or conversely results from the joint space narrowing and associated osteoarthritic changes. Joint space narrowing and meniscal subluxation may be interdependent, so that once subluxation is established in a knee, progressive articular cartilage loss and joint space narrowing occurs. Only a longitudinal study will resolve whether meniscal subluxation causes joint space narrowing. Our findings are relevant to OA research, in part, because radiographic joint space narrowing is a central outcome measure in ongoing clinical trials in OA and used routinely in clinical practice. Some of the progressive joint space narrowing in these longitudinal studies may be due to meniscal subluxation and not necessarily hyaline cartilage loss.

By design, this study included subjects as controls regardless of their radiographic OA status, based only on their asymptomatic state. This design permitted us to evaluate the association of subluxation with knee symptoms (cases vs. controls) and with structured OA (controls with and without X-ray OA). In controls with radiographic joint space narrowing, subluxation was common, but in controls without radiographic narrowing, severe subluxation was rare. This suggests that subluxation is associated with the development of structural osteoarthritis and does not necessarily induce symptoms in those with structural OA.

A model for understanding the impact of meniscal subluxation on the development of OA can be derived from the effect of complete meniscectomy. Following complete meniscectomy, the contact area between the tibia and femur, over which compressive stress is distributed decreases by approximately 40%.[17–19] The contact area and the contact stress experienced by the articular cartilage are inversely proportional. Without the energy absorbing function of the meniscus, the markedly increased contact contributes significantly to articular cartilage loss as well as remodeling of bone.[20] Following complete meniscectomy there is also loss of stability within the knee joint, which may contribute to the accelerated osteoarthritis in patients with a history of complete meniscectomy. We hypothesize that with increasing meniscal subluxation, there may be increasing contact stress on the articular cartilage of the femur and tibia. We are unable to suggest a threshold that represents pathologic subluxation and suggest, for the time being, measurement on a continuum.

Joint space narrowing on weight bearing radiographs has usually been ascribed to loss of articular cartilage. Experimentally, a normal meniscus compresses only 1–2 mm in height while under load. Therefore, meniscal compression contributes little to the appearance of joint space narrowing. It is possible, however, that progressive loss of meniscal volume within the joint space leads to articular cartilage wear, and that these two factors in combination account for the radiographic appearance of joint space narrowing. We suspect that early joint space narrowing may be due more to loss of meniscal height secondary to subluxation than to articular cartilage loss, especially in the periphery of the joint where hyaline cartilage is the thinnest and meniscus the thickest. This hypothesis is supported by the observation that only 15% of the controls with less than 3-mm meniscal subluxation demonstrated joint space narrowing.

The type and degree of anatomic derangement necessary to permit significant medio-lateral meniscal subluxation is uncertain. The attachments of the meniscus to the surrounding bone and soft tissues are complex and probably contribute to the relative lack of significant subluxation in normals. For the medial meniscus, these include anterior and posterior attachments to the tibia, attachments to the medial collateral ligament, and to the coronary ligament. For the meniscus to translocate, there are probably several anatomic conditions necessary including laxity in the medial collateral ligament and possibly other meniscal attachments.

Perhaps just as important as the surrounding soft tissues for the stability of the meniscus is the intrinsic structure of the meniscus. Circumferentially oriented collagen fibers in the meniscus provide significant resistance to hoop stress. The hoop stresses found within the meniscus counteract the compressive forces generated on the meniscus by the tibia and femur and the resultant tendency to radial meniscal displacement. A single cut or tear to the radial edge of the meniscus eliminates these hoop stresses and contributes to medio-lateral subluxation of the meniscus.[18] Many subjects with significant meniscal subluxation may have either radial tears or equivalent, specifically sufficient degenerative change within their meniscus that the circumferentially oriented collagen is disrupted.

There are several limitations to the present study. First, as indicated above, the cross sectional nature of this study precludes definitive etiologic inferences. Second, the amount of meniscal subluxation may be underestimated in both cases and controls because the knee MRI exams were non-weight bearing. Third, the direction of meniscal subluxation is not exclusively medial or lateral. Because nearly all the measurements of subluxation were obtained on the anterior half of the coronal images containing the tibial plateau, there may have been a component of anterior subluxation as well. Subluxation was measured on the coronal MR images as opposed to sagittal images because of ease and reproducibility. Fourth, we did not evaluate the anatomic conditions such as joint effusion, meniscal tear or internal derangements that contribute to meniscal subluxation. Lastly, we can not be certain our results are generalizable beyond the veterans population we studied.

In conclusion, our data show that meniscal subluxation is a prominent feature of knee OA and contributes to the appearance of joint space narrowing.

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