Effect of Local Alignment on Compartmental Patterns of Knee Osteoarthritis

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Background: Previous studies have shown that lower-extremity malalignment increases the risk and rate of progression of knee osteoarthritis. The authors of such studies have used full-length lower-extremity radiographs to quantify alignment. However, a radiograph that includes only the knee is commonly ordered for a patient with early symptoms of knee osteoarthritis. The purpose of this study was to investigate whether local malalignment, as determined with use of a standing short knee radiograph, is associated with an increased risk of having osteoarthritis and having more severe compartmental disease.

Methods: Short fluoroscopically guided standing anteroposterior knee radiographs of 306 patients (608 knees) with radiographic evidence of knee osteoarthritis were used to determine the compartment-specific Kellgren-Lawrence grade of osteoarthritis and the local (distal femoral to proximal tibial) knee alignment. The relationship between local alignment and compartmental patterns of osteoarthritis was assessed.

Results: Each degree of increase in the local varus angle was associated with a significantly increased risk of having predominantly medial compartment osteoarthritis, even when we adjusted for age, sex, and body mass index (odds ratio, 1.39; 95% confidence interval, 1.29 to 1.49; $p < 0.001$). A similar association was found between valgus angulation and lateral compartment osteoarthritis (odds ratio, 1.55; 95% confidence interval, 1.36 to 1.75; $p < 0.001$). Analysis of the 362 knees with predominantly medial compartment osteoarthritis showed that each degree of increase in the varus angle was associated with a significantly increased adjusted risk of having severe medial disease (odds ratio, 1.52, $p < 0.001$). In the forty-seven knees with predominantly lateral compartment osteoarthritis, a similar trend was found between an increase in the valgus angle and the severity of the lateral disease, with the results approaching but not reaching significance.

Conclusions: In patients with early symptomatic knee osteoarthritis, there is a clear relationship between local knee alignment, as determined from short standing knee radiographs, and the compartmental pattern and severity of the knee osteoarthritis. This study provides data with which physicians can assess how knee alignment contributes to the observed patterns and severity of osteoarthritis in an individual patient.

Level of Evidence: Prognostic Level II. See Instructions to Authors for a complete description of levels of evidence.

It has previously been shown that varus malalignment of the lower limb increases the risk of progression of osteoarthritis in the medial compartment of the knee and that an increasing varus angle is associated with more severe progression of medial disease¹. Similarly, valgus malalignment increases the risk of progression of lateral disease, and an increasing valgus angle is associated with more severe progres-

sion of lateral disease¹. Those findings and similar previous investigations of limb alignment and compartmental osteoarthritis²⁻⁴ were based on full-length radiographs that included the whole lower extremity. Varus, valgus, and neutral knee alignment were defined on the basis of the hip-knee-ankle angle, which requires visualization of all three joints^{1-3,5}. This approach is advantageous in the research setting and perhaps

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also for some patients with advanced disease requiring surgical treatment⁶. However, acquiring full-length radiographs is not common in the clinical evaluation of patients with early knee osteoarthritis. Instead, the physician usually obtains only knee radiographs (that is, radiographs that do not include the hip and ankle joints)⁷. Despite this common clinical practice, very little has been written about the relationship between local alignment (the distal femoral-proximal tibial angle measured on a short knee radiograph) and observed patterns and severity of compartmental knee osteoarthritis.

The purpose of this study was therefore to assess the risk of having compartment-specific knee osteoarthritis on the basis of a short standing anteroposterior knee radiograph made with the knee flexed 10° to 30°. We hypothesized that there is a relationship between knee alignment as determined from these radiographs and patterns of compartmental osteoarthritis in much the same way as there is such a relationship between overall lower-extremity alignment determined from full-length radiographs and patterns of compartment osteoarthritis. The principal advantage of finding such an association is its applicability to the common scenario of a physician using a short knee radiograph of a patient with early knee osteoarthritis to determine the impact of alignment on the pattern and severity of disease.

Materials and Methods

Study Design

The research proposal was approved by the Mayo Clinic institutional review board. A total of 306 community-dwelling individuals were recruited as volunteers for a larger

study performed to prospectively evaluate the effects of exercise on knee osteoarthritis. Enrollment was sought with use of advertisement both inside and outside of the Mayo Clinic designed to seek individuals from the greater Rochester, Minnesota, area. Potentially eligible individuals were those with reported chronic, stable, and primarily idiopathic osteoarthritis of at least one knee with Kellgren-Lawrence⁸ radiographic grade-1, 2, 3, or 4 changes in whom the involved joint(s) was the primary factor limiting physical or functional activity. Subjects were invited to participate in the study if they met specific eligibility criteria (Table I). Once it had been determined that the potential subject met the inclusion and exclusion criteria, he or she was asked to sign an informed-consent form.

Radiography

Computed radiography in the anteroposterior direction was performed on each knee with the subject standing with the knee in a semiflexed posture (in 10° to 30° of flexion)^{9,10}. A fluoroscopy system (MD4; Philips Medical Systems, Eindhoven, The Netherlands) was used for positioning to ensure that the center of the x-ray beam corresponded to the center of the joint space (thus controlling for rotation) and that the tibial plateau was horizontal and parallel to the beam. As many as three fluoroscopic spot views were required to achieve optimal positioning. Weight-bearing lateral radiographs were also made to assess arthritic changes in the patellofemoral joint. Images were acquired with use of a Fuji 5000 Plus Reader with a 36 × 43-cm Fuji ST-VI CR imaging plate (Fuji Medical Systems, Tokyo, Japan).

TABLE I Inclusion and Exclusion Criteria for Participation in the Study

Inclusion Criteria	Exclusion Criteria
<p>≥30 years of age</p> <p>Current symptoms of chronic stable (for 6 mo) pain and/or stiffness in one or both knees during weight-bearing activities</p> <p>Involved joint primary factor limiting physical or functional activity</p> <p>Radiographic signs of mild or moderate arthritis</p> <p>Mild joint space narrowing (>2 mm remaining)</p>	<p>Current participation in a regular exercise program</p> <p>Existing medical condition that would preclude increased physical activity</p> <p>Ligamentous instability of more than Grade I*</p> <p>Asymptomatic osteoarthritis of both knees, incapacitating arthritis or inflammatory arthritis</p> <p>Major lower-extremity-joint reconstructive surgery</p> <p>Involvement of multiple major joints, if another joint is more functionally limiting than knee</p> <p>Any condition that severely limits ability to walk, such as amputation or stroke</p> <p>Gait aids used majority of time for walking</p> <p>Cannot use step-over-step techniques for either ascending or descending stairs</p> <p>Not able to undergo magnetic resonance imaging; for example, because of cardiac pacemaker</p> <p>Dementia or inability to give informed consent</p>

*The grading system is described in: American Medical Association. Standard nomenclature of athletic injuries. Chicago: American Medical Association; 1968.

The radiographs were graded by a board-certified radiologist (K.K.A.). The Kellgren-Lawrence scale⁸ was applied individually to the medial tibiofemoral, lateral tibiofemoral, and patellofemoral compartments. Knees were identified as having predominantly medial disease if they had (1) only medial involvement, (2) only medial and patellofemoral involvement, or (3) involvement of the medial and lateral compartments (with or without patellofemoral involvement) but with the medial involvement more severe than the lateral involvement according to the compartment-specific Kellgren-Lawrence score. Predominantly lateral disease was defined in an analogous manner. Severe osteoarthritis in a given compartment was defined as a Kellgren-Lawrence score in that compartment of 3 or 4; mild-to-moderate osteoarthritis was defined as a Kellgren-Lawrence score in that compartment of 1 or 2.

Analysis of Local Alignment

The local anatomic tibiofemoral angle was determined with use of a method similar to that described by Kraus et al.⁵ and by Hsu et al.¹¹ (Fig. 1). The femoral shaft was bisected at a point approximately 10 cm proximal to the knee joint, the center of the intercondylar notch was identified, and the two points were connected. Similarly, the tibial shaft was bisected approximately 10 cm distal to the knee joint, the center of the intercondylar eminence was identified, and the two points were connected. The exact distance from the knee joint center at which the femur or tibia was to be bisected was determined on the basis of the size of the patient—i.e., a length 1.3 times that of the epicondylar line (from the medial epicondyle to the lateral epicondyle) was used. This distance was approximately 10 cm from the knee joint center for the vast majority of knees, making it quite consistent with the method used by Kraus et al.⁵. To simplify the analysis of more than 500 knee radiographs and to minimize variability, a custom-written semi-automated computer program (MATLAB; The MathWorks, Natick, Massachusetts) was used. The alignment of the knee was calculated as 180 minus the lateral angle between the femoral and tibial vectors: a valgus knee resulted in a positive angle, and a varus knee resulted in a negative angle. All alignment analyses were performed by one of the authors (F.A.K.).

Final Study Sample and Demographics

Three hundred and six patients were enrolled. Most patients (232, 75.8%) were women. Two hundred and ninety-seven (97.1%) of the 306 patients were white, four (1.3%) were Asian, and five (1.6%) were Hispanic. The age of the patients ranged from thirty-one to eighty-one years, with a mean (and standard deviation) of 56.7 ± 10.6 years. The body mass index ranged from 20.0 to 55.5 kg/m², with a mean of 31.7 ± 6.6 kg/m².

Four patients had radiographic evidence of osteoarthritis in only one knee; thus, the study included 608 knees with radiographic evidence of osteoarthritis. Of these 608 knees, 402 (66%) had some evidence of disease in all three compartments, fifty-five (9%) had only medial involvement, seventy-six (13%) had only medial and patellofemoral involvement, seven (1%)

Fig. 1

The method of calculating the local tibiofemoral alignment angle on a short anteroposterior knee radiograph. The distal femoral anatomic axis is defined by connecting the intercondylar notch to the mediolateral center of the femoral shaft at a point approximately 10 cm proximal to the knee joint. The proximal tibial anatomic axis is defined by connecting the center of the intercondylar eminence to the mediolateral center of the tibial shaft at a point approximately 10 cm distal to the knee joint. The acute angle that is formed between these two lines is equal to the local anatomic tibiofemoral alignment angle. While we used semiautomated computer analysis because of the large volume of radiographs needed to be analyzed in this study, the procedure can be reproduced readily by manual techniques in the clinical setting.

had only lateral and patellofemoral involvement, forty-two (7%) had only medial and lateral involvement, and twenty-six (4%) had only patellofemoral involvement. No knee had only lateral involvement. Three hundred and sixty-six (60%) of the 608 knees had predominantly medial involvement and forty-

TABLE II Risks of Having Predominantly Medial or Predominantly Lateral Osteoarthritis Among All Knees

		Univariate Analysis			Multivariate Analysis		
Variable	No. of Knees	Odds Ratio	95% Confidence Interval for Odds Ratio	P Value	Odds Ratio	95% Confidence Interval for Odds Ratio	P Value
Medial osteoarthritis							
Varus angle (<i>per deg</i>)	600	1.39	1.29, 1.50	<0.001	1.39	1.29, 1.49	<0.001
Age (<i>per yr</i>)	600	1.02	1.01, 1.04	0.008	1.02	1.00, 1.04	0.05
Female	459	1.0	—	—	1.0	—	—
Male	141	1.26	0.79, 2.01	0.33	0.88	0.51, 1.52	0.65
Body mass index							
18.5-24.9	84	1.0	—	—	1.0	—	—
25-29.9	182	0.69	0.35, 1.33	0.27	0.79	0.38, 1.65	0.53
≥30	334	1.10	0.59, 2.03	0.77	0.96	0.48, 1.95	0.92
25-29.9	182	1.0	—	—	1.0	—	—
≥30	334	1.60	1.02, 2.50	0.04	1.22	0.75, 1.98	0.42
Lateral osteoarthritis							
Valgus angle (<i>per deg</i>)	600	1.54	1.35, 1.76	<0.001	1.55	1.36, 1.75	<0.001
Age (<i>per yr</i>)	600	0.99	0.96, 1.01	0.32	0.99	0.96, 1.02	0.33
Female	459	1.0	—	—	1.0	—	—
Male	141	0.55	0.20, 1.52	0.25	0.80	0.27, 2.37	0.68
Body mass index							
18.5-24.9	84	1.0	—	—	1.0	—	—
25-29.9	182	4.22	0.94, 19.07	0.06	4.25	0.99, 18.35	0.05
≥30	334	3.75	0.87, 16.19	0.08	5.05	1.27, 20.00	0.02
25-29.9	182	1.0	—	—	1.0	—	—
≥30	334	0.89	0.42, 1.89	0.76	1.19	0.49, 2.84	0.70

nine (8%) had predominantly lateral involvement, as defined above. Of the 608 knee radiographs, eight were too short on either the femoral or the tibial side for semiautomated computer analysis of local knee alignment (that is, they depicted less of the tibial and/or femoral shaft than the required 1.3 times the length of the epicondylar line), and they were thus excluded from the analysis. This left 600 knees that were analyzed in this study.

This was a cross-sectional study designed to assess an association, not a causal relationship, between compartmental patterns of knee osteoarthritis and local alignment.

Statistical Methods

Four outcomes were assessed in this analysis: whether a knee had predominantly medial osteoarthritis as compared with other types of osteoarthritis, whether a knee had predominantly lateral osteoarthritis as compared with other types of osteoarthritis, whether a knee had severe medial osteoarthritis as opposed to mild-to-moderate medial osteoarthritis, and whether a knee had severe lateral osteoarthritis as opposed to mild-to-moderate lateral osteoarthritis. The third and fourth outcomes were assessed only among patients with predominantly medial osteoarthritis and predominantly lateral osteoarthritis, respectively.

An increasing varus or valgus angle was the primary risk factor of interest for these outcomes. In addition, we

considered age, sex, and body mass index as possible risk factors.

The body mass index was assessed as a categorical variable with use of current categorizations (18.5 to 24.9 kg/m² = normal, 25 to 29.9 kg/m² = overweight, and ≥30 kg/m² = obese)¹². All four risk factors were assessed in univariate and multivariate analyses. Most patients in this study had osteoarthritis in both knees. To account for the correlation between the two knees of a single patient, generalized estimating equations were used within logistic regression in a generalized linear models framework to obtain accurate estimates of the standard errors of the parameter estimates. Odds ratios with 95% confidence intervals, the c-statistic, and p values are reported for each model. The c-statistic estimates a model's effectiveness. It is a measure of concordance ranging from 0 to 1; values close to 1 indicate that the model almost perfectly discriminates between the subjects in the two outcome groups (for example, those with predominantly medial osteoarthritis compared with those with other patterns of osteoarthritis), whereas values close to 0.5 suggest that the predictive ability of the model is no better than chance alone. For continuous variables, the odds ratio can be interpreted as the change in the risk of the knee having the outcome for each unit increase of the variable; for categorical variables, the odds ratio is the change in the risk of the knee in that category having the

Fig. 2-A

Fig. 2-B

Figs. 2-A and 2-B The effect of the local tibiofemoral angle (determined on a short anteroposterior knee radiograph) on the observed compartmental patterns of knee osteoarthritis. **Fig. 2-A** Univariate analysis of the probability that a patient with early knee osteoarthritis has predominantly medial or lateral disease as a function of local knee alignment. The plot demonstrates that increasing varus angulation (as determined on a short knee radiograph) increases the probability of that knee having predominantly medial osteoarthritis. An analogous result for valgus angulation and lateral osteoarthritis is also depicted. The vertical line represents an approximation of normal local alignment on the basis of data on men and women twenty-five to sixty years of age, from the study by Hsu et al.¹¹ **Fig. 2-B** Univariate analysis of the probability that a knee with predominantly medial osteoarthritis (OA) will have more severe disease (Kellgren-Lawrence grade 3 or 4) rather than mild-to-moderate disease (grade 1 or 2) as a function of local knee alignment. The plot demonstrates that increasing local varus angulation increases the risk of that knee having more severe medial disease. Corresponding results for valgus angulation and lateral disease approached but did not reach significance and are thus omitted from this graph. The vertical line represents an approximation of normal local alignment on the basis of data on men and women twenty-five to sixty years of age, from the study by Hsu et al.¹¹. The red lines indicate the 95% confidence interval.

TABLE III Risks of Having Severe Rather Than Mild-to-Moderate Medial or Lateral Disease Among Patients with Predominantly Medial or Lateral Osteoarthritis, Respectively

		Univariate Analysis			Multivariate Analysis		
Variable	No. of Knees	Odds Ratio	95% Confidence Interval for Odds Ratio	P Value	Odds Ratio	95% Confidence Interval for Odds Ratio	P Value
Medial osteoarthritis							
Varus angle (<i>per deg</i>)	362	1.49	1.33, 1.67	<0.001	1.52	1.35, 1.72	<0.001
Age (<i>per yr</i>)	362	1.03	1.01, 1.06	0.005	1.05	1.02, 1.08	0.003
Female	271	1.0	—	—	1.0	—	—
Male	91	0.84	0.48, 1.45	0.53	0.45	0.24, 0.85	0.01
Body mass index							
18.5-24.9	52	1.0	—	—	1.0	—	—
25-29.9	96	1.49	0.61, 3.63	0.38	1.76	0.64, 4.89	0.28
≥30	214	3.67	1.66, 8.13	0.001	3.85	1.44, 10.29	0.007
25-29.9	96	1.0	—	—	1.0	—	—
≥30	214	2.46	1.35, 4.49	0.003	2.19	1.15, 4.16	0.02
Lateral osteoarthritis							
Valgus angle (<i>per deg</i>)	47	1.09	0.94, 1.26	0.24	1.19	0.94, 1.52	0.15
Age (<i>per yr</i>)	47	0.97	0.91, 1.03	0.35	0.93	0.83, 1.03	0.17
Female	40	1.0	—	—	1.0	—	—
Male	7	1.21	0.35, 4.14	0.77	2.07	0.27, 15.75	0.48
Body mass index							
18.5-24.9	2	1.0	—	—	1.0	—	—
25-29.9	17	0.70	0.04, 13.63	0.81	1.24	0.08, 20.27	0.88
≥30	28	1.55	0.08, 28.46	0.77	3.16	0.19, 51.85	0.42
25-29.9	17	1.0	—	—	1.0	—	—
≥30	28	2.21	0.55, 8.88	0.26	2.56	0.58, 11.29	0.22

outcome relative to the reference group. The reference group for sex was female, and the reference group for body mass index was a value in the normal range (18.5 to 24.9 kg/m²). For all analyses, *p* values of <0.05 were considered significant.

Plots indicating the probability of having predominantly medial or lateral osteoarthritis and the probability of having more severe medial or lateral osteoarthritis as a function of an increasing varus or valgus angle, respectively, were constructed if corresponding results in the univariate analysis reached significance.

Results

An increase in the varus angle was associated with a significantly increased risk of having predominantly medial compartment osteoarthritis (Table II). In the multivariate analysis, in which we accounted for age, sex, and body mass index in addition to the varus angle, for each 1° increase in varus angulation, there was a 39% increase in the chance that the medial compartment would be the predominantly affected compartment (odds ratio, 1.39; 95% confidence interval, 1.29 to 1.49; *p* < 0.001; concordance, 0.75). Similar results were found in the univariate analysis. A univariate-based plot of varus angle versus the probability of having predominantly medial compartment osteoarthritis revealed that this probability steadily increases as varus angulation becomes more severe (Fig. 2-A).

Similarly, an increase in the valgus angle was associated with a significantly increased risk of having predominantly lateral compartment osteoarthritis (Table II). In the adjusted multivariate analysis, for each 1° increase in valgus angulation, there was a 55% increase in the chance that the lateral compartment would be the predominantly affected compartment (odds ratio, 1.55; 95% confidence interval, 1.36 to 1.75; *p* < 0.001; concordance, 0.80). There were similar findings in the univariate analysis. A univariate-based plot of valgus angle versus the probability of having predominantly lateral compartment osteoarthritis revealed that this probability steadily increases as valgus angulation becomes more severe (Fig. 2-A).

Among the 362 knees that had predominantly medial compartment osteoarthritis, an increase in the varus angle was associated with a significantly increased risk of having more severe medial disease (that is, Kellgren-Lawrence grade 3 or 4 rather than Kellgren-Lawrence grade 1 or 2) (Table III). In the adjusted multivariate analysis, for each 1° increase in varus angulation, there was a 52% increase in the chance that the knee would have severe medial osteoarthritis rather than mild-to-moderate medial osteoarthritis (odds ratio, 1.52; 95% confidence interval, 1.35 to 1.72; *p* < 0.001, concordance, 0.83). The findings were similar in the univariate analysis. A univariate-based plot of varus angle versus the probability of having severe

medial osteoarthritis among knees with predominantly medial osteoarthritis revealed that this probability steadily increases as varus angulation becomes more severe (Fig. 2-B).

Among the forty-seven knees that had predominantly lateral compartment osteoarthritis, there was a trend toward an association between an increasing valgus angle and having more severe lateral disease (Table III). Although the results of the unadjusted univariate analysis did not reach significance, the adjusted multivariate analysis demonstrated that each degree of increase in the valgus angle was associated with a 19% increase in the risk of having severe rather than mild-to-moderate lateral disease, with the results indicating a trend toward significance (odds ratio, 1.19; 95% confidence interval, 0.94 to 1.52; $p = 0.15$; concordance, 0.78). The lack of significance as well as the only modest increase in risk (that is, 19%) likely stems from the fact that the study was underpowered with regard to the group with lateral compartment osteoarthritis. However, it is important to note that all odds ratios reported here are for a 1° change in the knee angle. Although not significant, the above findings suggest that a person in the 75th percentile (8.7° of valgus) is 2.5 times more likely to have severe rather than mild-to-moderate lateral disease than someone in the 25th percentile (3.5° of valgus) (odds ratio, 2.5; 95% confidence interval, 1.99 to 3.23).

We controlled for age, sex, and body mass index by performing both univariate and multivariate analyses (Tables II and III). Increasing age was weakly associated with an increase in the risk of having predominantly medial osteoarthritis in both the univariate and the multivariate analysis (odds ratio, 1.02; 95% confidence interval, 1.00 to 1.04; $p = 0.05$), but these magnitudes were so small that they were not likely to be clinically relevant. Moreover, increasing age was not associated with an increased risk of having predominantly lateral osteoarthritis in either the univariate or the multivariate analysis. Similarly, increasing age was weakly associated with an increased risk of having severe rather than mild-to-moderate medial osteoarthritis among patients with predominantly medial osteoarthritis in both the univariate and the multivariate analysis (odds ratio, 1.05; 95% confidence interval, 1.02 to 1.08; $p = 0.003$), but these magnitudes are also unlikely to be clinically relevant. Increasing age was not associated with a significantly increased risk of having severe rather than mild-to-moderate lateral osteoarthritis among patients with predominantly lateral osteoarthritis in either the univariate or the multivariate analysis.

Being male was not associated with a significantly different risk of having either medial or lateral osteoarthritis in either the univariate or the multivariate analysis (Table II). Being male also was not associated with a significantly different risk of having severe rather than mild-to-moderate medial osteoarthritis among patients with predominantly medial osteoarthritis in the univariate analysis, but it was weakly associated with a decreased risk in the multivariate analysis (odds ratio, 0.45; 95% confidence interval, 0.24 to 0.85; $p = 0.01$) (Table III). In addition, being male was not associated with a significantly different risk of having severe rather than mild-

to-moderate lateral osteoarthritis among patients with lateral osteoarthritis in either the univariate or the multivariate analysis.

Discussion

In this cross-sectional study, we investigated the relationship between local knee alignment and compartmental disease and found that worsening local varus alignment is associated with a significantly increased risk both of having predominantly medial disease and of having more severe medial disease among knees with predominantly medial osteoarthritis. Similarly, we found that worsening local valgus alignment is associated with a significantly increased risk of having predominantly lateral disease. Although previous studies have documented significant relationships between alignment and compartment disease¹⁻⁴, the authors based their determination of alignment on full-length lower-extremity radiographs. Such radiographs expose the patient to higher amounts of radiation, require greater technical expertise on the part of the radiology technician, and are more expensive than short knee radiographs⁵. For this reason, it is a common clinical scenario for physicians treating early knee osteoarthritis to base their assessment, prognosis, and treatment plans on radiographs that include only the knee⁷. However, previous reports in the literature suggested that these physicians are not able to accurately determine the impact of alignment, which has been cited as one of the most important risk factors for progression of osteoarthritis^{1,13}, on many of their patients with knee osteoarthritis.

In this study, we focused on a more realistic clinical scenario of using a standing short knee radiograph alone to determine alignment. Although our approach was not entirely indicative of common clinical practice (for example, we utilized fluoroscopy for positioning), our lack of reliance on full-length radiographs constitutes an important difference from prior studies that makes our technique more applicable to everyday practice. Angulation was determined strictly from a standing short knee radiograph, and this determination can be reproduced readily in the clinical setting⁹. Even though this study is a cross-sectional analysis in which we looked at radiographs made at only one point in time, the results parallel those in the studies in which the authors used full-length radiographs, including that of Sharma et al.¹. Worsening alignment is associated with an increased risk of knee-compartment-specific degenerative changes.

It is not surprising that our results agree with those in the previous literature. There is a clear relationship between overall limb alignment (as determined from full-length radiographs) and compartment osteoarthritis of the knee. It is reasonable to expect similar relationships between local alignment and compartmental patterns of knee osteoarthritis. For example, Kraus et al. showed a clear correlation between overall limb alignment determined from full-length radiographs and local alignment determined from short knee radiographs in a population of patients with early knee osteoarthritis⁵. Hsu et al. recognized a similar relationship between local alignment and overall limb alignment in normal subjects¹¹.

There are some important differences between our study and those in the literature. In the published studies in which full-length radiographs were used, the knees were frequently categorized, on the basis of absolute values, as normal, with pathological varus, or with pathological valgus¹⁻⁴. This was done readily because there were already well-established definitions of alignment as measured on full-length radiographs. Typically, varus is defined as hip-knee-ankle alignment of $>0^\circ$; neutral, as alignment of 0° ; and valgus, as alignment of $<0^\circ$ ^{11,14,15}. Since our method of determining alignment on short radiographs is much less well established, absolute values for varus and valgus as measured on short radiographs are difficult to ascertain from the literature and were not included in this analysis.

This study did have some important limitations. First, because we performed only a cross-sectional analysis, our findings are not sufficient to establish a causal relationship between local alignment and compartment knee osteoarthritis. Determining a true causal relationship would require a prospective longitudinal study. Although practical limitations prevented us from conducting that type of study, our demonstration of an association between local alignment and compartment osteoarthritis in a cross-sectional analysis may at least set the stage for the performance of prospective studies to assess this relationship. Another limitation of this study is that rotation was controlled in a highly accurate way by means of fluoroscopic positioning of the knee prior to acquisition of the radiographs. This gives rise to some concern regarding the applicability of our results to the typical clinical setting, in which fluoroscopy is not routinely utilized. Although we acknowledge that this is a clear limitation of our study and that future studies done without the use of fluoroscopy would certainly be beneficial, the fact that the literature has shown the findings on nonfluoroscopically guided radiographs to be similar to those on fluoroscopically guided radiographs affords some degree of reassurance concerning our results¹⁶. Another important point to consider is that our anteroposterior radiographs were made with the subject bearing weight with approximately 20° of knee flexion. Although a typical anteroposterior knee radiograph used to evaluate a patient for early knee osteoarthritis is weight-bearing, it is usually made with the knee in full extension. The degree of flexion utilized in our technique may have had some effect on the determination of alignment^{17,18}.

Our use of the Kellgren-Lawrence scale as a measure of disease severity is also a limitation of this study¹. We attempted to control for this by grouping grades 3 and 4 together (severe disease) and grades 1 and 2 together (mild-to-moderate disease). In this way, differences between severe and mild-to-

moderate disease are much more likely to indicate a real change in radiographic evidence of disease progression than would have been the case if each of the four grades had been considered separately. Furthermore, although the Kellgren-Lawrence scale is widely regarded as accurate and scientific, it is likely that in an everyday clinical setting most orthopaedic surgeons utilize joint space narrowing as the predominant variable indicating the presence and degree of arthrosis. Because we did not specifically utilize joint space narrowing alone for this purpose, our results may in principle not be applicable to settings in which this method is used. However, given that other studies¹⁹ have shown strong agreement between grading systems emphasizing joint space width (for example, Ahlbäck's system²⁰) and the Kellgren-Lawrence system, it is likely that we would have arrived at similar conclusions had we used the perhaps more familiar method of measuring joint space narrowing instead of a formal Kellgren-Lawrence analysis.

Finally, it is important to point out that the results of our study do not in any way indicate that short knee radiographs alone should be used as a template for osteotomy. As mentioned, the literature has a scarcity of data indicating the normal local alignment angle when short knee radiographs alone are used.

The cross-sectional nature of the current study and utilization of fluoroscopic positioning are important limitations and thus suggest the need for future studies. Nonetheless, this report provides data for the physician faced with the common clinical scenario of using a short knee radiograph to assess how a patient's knee alignment contributes to the observed patterns and severity of osteoarthritis. ■

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