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Knee alignment differences between Chinese and Caucasian subjects without osteoarthritis

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Abstract

Objective—Despite the lower prevalence of obesity (a known risk factor for osteoarthritis (OA)), the prevalence of lateral tibiofemoral OA is higher in Chinese communities compared with Caucasian communities. One potential explanation is the difference in knee alignment between the two populations. We measured various knee alignment indices among Chinese and Caucasians and assessed whether these indices were different between the two racial groups.

Methods—We selected participants from the Framingham Osteoarthritis Study (FOA) and the Beijing Osteoarthritis Study (BOA), all without knee OA (Kellgren & Lawrence grade <2). Bilateral, fully extended anteroposterior knee radiographs were measured for the following angles in both knees: the anatomic axis (AA), the condylar angle (CA), the tibial plateau angle and the condylar–plateau angle (CP). We compared the mean of each measurement between the two racial groups adjusting for age and body mass index using linear regression and stratified by sex.

Results—The mean AA, CA and CP were significantly different in the BOA compared with the FOA. For women, the mean AA and CA were significantly more valgus in BOA subjects, while in men, the mean AA and CP were more valgus in BOA subjects.

Conclusions—There are significant differences in knee morphology between Chinese and Caucasian cohorts, which result in a more valgus alignment of the distal femur in Chinese. This would serve to shift the mechanical loading towards the lateral compartment, and provide a possible explanation why Chinese have a higher prevalence of lateral tibiofemoral OA.

The aetiopathogenesis of osteoarthritis (OA) is widely believed to be the result of local mechanical factors acting within the context of systemic susceptibility. The importance of mechanical factors may explain why knee OA occurs more often in the medial compartment than in the lateral compartment, presumably due to its increased loading during gait.¹ The medial compartment absorbs 60–70% of the force across the knee during weight bearing.² In theory, any shift from a neutral or collinear alignment of the hip, knee and ankle affects load distribution at the knee and could potentially influence the pattern of tibiofemoral involvement in OA.³ Knee alignment is a key determinant of the disproportionate medial transmission of load, and can predict OA progression.⁴⁵

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Epidemiological studies exploring the racial or geographic distribution of a disease often provide valuable clues about potential aetiological factors. Recent studies have shown remarkable differences in the patterns of OA between Chinese in Beijing and white people in Framingham, USA.⁶⁻⁸ In particular, the Chinese cohort had an equal (men) or higher (women) prevalence of knee OA than the US population despite a lower mean body mass index (BMI), long thought to be a major risk factor.⁷ Furthermore, the prevalence of lateral tibiofemoral (LTF) OA particularly among women was much greater than in the Caucasian sample (28.5% vs 11%).⁶ Examination of the anatomic axis in a small sample of the cohort of the Beijing and Framingham populations did not explain the higher LTF OA prevalence in Chinese, especially that among women.⁶ The reasons for the differences in patterns of TF OA between the Beijing and Framingham sample were hypothesised to be from such factors as lifestyle (OA as a consequence of physical labour and squatting), but no clear conclusions could be made.⁶

In this study, we sought to apply a more comprehensive assessment of alignment to the same Beijing and Framingham cohorts. This includes measurement of the anatomic axis angle as well as condylar and tibial plateau angles (detailed below). Based on work by Cooke and others, these additional angles may add important additional information not gained by simply measuring the anatomic axis.^{9,10} We hypothesised that we would find differences in condylar angle between the groups and that this may be more important in considering alignment than the overall anatomic axis. Furthermore, the presence of this difference in alignment will allow further elucidation of the aetiology of compartment-specific knee OA.

METHODS

Study participants

This cross-sectional analysis drew from two studies described below.

The Beijing Osteoarthritis Study (BOA)—The BOA was a population-based cross-sectional study conducted between 1997 and 2000.^{7,9} The main goal of the study was to compare the prevalence of OA between Chinese in Beijing and white people in the USA and to explore if the prevalence of traditional risk factors was different between the two racial groups. The subjects were recruited from residents aged 60 years and older in the four central districts in Beijing, all of Chinese ancestry. Details of sampling frame, recruitment and study design have been published previously.⁷

For the first 1800 subjects, weight-bearing anteroposterior (AP) radiographs were obtained for both knees. For the last 700 subjects, the posteroanterior view was used instead of the AP view. For this analysis we drew only from participants who underwent weight-bearing AP radiographs to ensure consistency with the radiographic acquisition used in the Framingham Study (see below).

The Framingham Osteoarthritis Study (FOA)—The Framingham Study began in 1948 in Framingham, MA (USA). The original purpose of the study was to evaluate risk factors for cardiovascular disease.¹¹ The sample used in this study was the Framingham Offspring Cohort. As part of a study on the inheritance of OA, participants in the Offspring Cohort were originally examined between 1992 and 1994 (Offspring examination 5). At this visit participants received a weight-bearing AP radiograph of both knees identical in protocol to the one acquired in the BOA.

Radiograph reading

Both studies used the same protocols to obtain AP knee radiographs in weight-bearing, with a 14 × 17-inch film and fully extended knees. One bone and joint radiologist read all the radiographs in the BOA and FOA studies. Each knee was evaluated for the presence of osteophytes and joint space narrowing on a 0–3 scale using the OARSI atlas.¹² Each knee was also graded for overall evidence of radiographic tibiofemoral OA using the Kellgren & Lawrence (K&L) grade on a 0–4 scale.¹³ The intra-rater weighted κ was 0.78 for the K&L grade.

Definition of radiographic tibiofemoral osteoarthritis

A knee was defined as having radiographic TF OA if its K&L grade was ≥ 2 on the AP knee radiograph. A subject was considered as having radiographic TF OA if he or she had at least one knee involved with radiographic TF OA.

Selection of sample

The selection of the sample from the FOA and BOA cohorts for this analysis was from participants without knee OA (K&L < 2), as the presence of OA – in particular the presence of joint space narrowing – may alter alignment. From these subjects without OA we randomly selected 354 participants from each group. All films from these random samples that were available digitally at the time of the study were measured, giving 231 participants in the FOA cohort and 340 participants in the BOA cohort.

Alignment measurements

The load-bearing axis is represented by a line drawn from the centre of the femoral head to the centre of the ankle. In a varus deformed knee, this line passes medial to the knee centre and an adduction moment arm is created, which increases force across the medial compartment. In a valgus deformed knee, the load-bearing axis passes lateral to the knee centre, and the resulting abduction moment arm increases force across the lateral compartment.³

Knee alignment has been characterised by measuring numerous angles within the joint.¹⁴ These include: (a) the mechanical axis (angle between lines drawn from the femoral head to the tibial spines and the line from the tibial spines to the mid-talus); (b) the anatomic axis (angle between lines drawn from the midpoint of the shaft of the femur through the tibial spines and the line from the tibial spines to the midpoint of the tibia); (c) the condylar angle (angle between the mechanical or anatomic axis line of the femur and a line tangent to the femoral condyles) (see fig 1); (d) the tibial plateau angle (angle between the mechanical or anatomic axis line of the tibia and a line tangent to the tibial plateau); and (e) the condylar–plateau angle (the angle between the above-mentioned tangent lines – condylar angle and tibial plateau angle) (see fig 1). The anatomic axis measurement does not require a full-length radiograph as does the mechanical axis, and these two measures have been highly correlated in previous studies.^{15,16}

Digital films were read using imaging software (eFilm Workstation (Version 2.0.0) software; Merge Healthcare, Milwaukee, Wisconsin, USA) allowing manual placement of lines and computer calculation of angles to measure the following angles depicted in fig 1.

1. Anatomical axis, in degrees from 180°, (a) the anatomic axis lines were drawn from the visual centre of the femur and tibia at a point 10 cm from joint line through the visual midpoint of the tibial spines.
2. Condylar angle in degrees from 90°, (a) the condylar line was drawn tangent to the most distal aspect of the femur.

3. Tibial plateau angle in degrees from 90°, (a) the tibial plateau line was drawn tangent to the most lateral aspect of the tibial plateau.
4. Condylar–plateau angle in degrees as measured between the condylar and tibial plateau tangent lines.

By convention, varus angles were recorded as negative numbers, while valgus angles were recorded as positive numbers. A single reader (WH) made the measurements on both knees from each film, and reader reliability was assessed from a subsample of subjects. All films were read blinded to study cohort, patient identifiers and patient symptom status. To evaluate for reader-drift, we re-assessed intra-rater reliability by inserting one original reliability *x*-ray for every 10 new *x*-rays read. Interobserver correlation coefficient ranged from 0.93 to 0.96 and intraobserver correlation coefficient from 0.94 to 0.97 for the different alignment measures.

Statistical methods

We used SAS software (Ver 9.1.3, SAS Institute Inc., Cary, NC, USA) to perform all statistical analyses. We examined the distributions of each angle in order to see if the distributions of each appeared normal. To examine the relative importance of measuring each of the angles, we did Pearson's correlations of each angle to the other angles, stratified by cohort and knee.

We calculated the mean and standard deviation of each alignment measurement for left and right knees separately according to sex and racial groups, and compared these indices between the two racial groups using Student's *t*-test. For each gender, we compared the proportion of knees with K&L grade 1 between the racial groups using χ^2 -test. We compared the difference of each measurement of knee alignment between two racial groups for men and women separately while adjusting for age and BMI using generalised estimating equations to account for the correlation between two knees.¹⁷ We also compared the variance of each alignment measurement between the two racial groups.

RESULTS

The characteristics of the subjects are presented in table 1. The mean age in the Beijing subjects was slightly older than the Framingham subjects. The Framingham subjects had a slightly higher mean BMI than the Beijing subjects. Figure 2 shows the distribution for the anatomic axis angle in the Framingham and Beijing subjects before adjusting for age and BMI. Note that in addition to the difference in the mean anatomic axis angle with more valgus alignment in Beijing subjects, the standard deviation of this measure in the Beijing subjects is larger compared with the Framingham subjects (F-test for equality of variances $p < 0.0001$). The distributions for the other angles are similar to that of the anatomic axis angle with a more valgus alignment and higher standard deviation in the BOA sample. Pearson's correlations showed that the anatomic axis angle and condylar angle are highly correlated with a range in correlation coefficients of 0.77–0.88 (all with $p < 0.0001$). Anatomic axis angle and tibial plateau angle had a moderate correlation of 0.36–0.49 (all with $p < 0.0001$). In the Framingham cohort, the anatomic axis angle had no significant correlation to the condylar–plateau angle, while in the Beijing cohort, there was a weak correlation (0.22, $p < 0.0001$). All other correlations were weak with a correlation coefficient < 0.25 .

Table 2 shows the comparison of the means, stratified by gender. The mean anatomic axis angle, condyle angle and condyle–plateau angle were significantly different in BOA compared with FOA. Although the mean anatomic axis angle was valgus in both cohorts, the BOA cohort was 1.35° more valgus ($p = 0.01$) in men and 2.01° more valgus ($p < 0.001$)

in women. The difference in mean condylar angle was more apparent in women (mean difference 1.69° , $p < 0.001$). The mean difference of the condylar angle in men was 0.15° ($p = 0.71$). The mean tibial plateau angle in both cohorts was in a varus direction although no statistically significant difference was observed between the two racial groups. Although subjects in both racial groups tended to have varus condylar–plateau angle, compared with Chinese, white people appeared to have more varus condylar–plateau angle, especially in men. (mean difference 0.80° , $p < 0.001$). The mean difference in the condylar–plateau angle in women approached significance (0.22° $p = 0.09$).

DISCUSSION

Our results showed that several knee morphological features are different between the Chinese and Caucasian subjects. These differences may lead to a more valgus alignment of the distal femur in Chinese. The condylar–plateau while in a varus direction in both racial groups, was less varus in Chinese. This would shift the mechanical loading towards the lateral compartment, and provide one potential explanation as to why the Chinese have a higher prevalence of LTF OA. Furthermore, as noted previously, the Beijing subjects also have a higher prevalence of medial tibiofemoral OA despite lower BMI. These seemingly contradictory statements might be explained by the larger variance seen in the Beijing cohort, although this is speculative in the absence of a longitudinal study design.

These results are not inconsistent with the results suggested by Felson *et al*⁶ who identified a mean anatomic axis angle of 4.5° in Framingham and 4.7° in Beijing. Because this sample included only 25 subjects from each cohort, this difference did not reach statistical significance. Our study has a much larger sample size and was therefore able to detect a difference. In addition, we measured more angles, which may help to differentiate the morphological source of these differences.

The contributions of alignment and other biomechanical angles to the pathology of knee OA has been suggested in several previous studies. Additional measures have been proposed to explain the relation of the femur and tibia and their articulating joint surfaces. The data on the correlation between the alignment measures in our study would suggest that there is little need to measure condylar angle as this is highly correlated with the anatomic axis. In contrast there do appear to be potential advantages afforded by measuring the tibial–plateau angle and condylar–plateau angle as these were less related and may provide additional unique information.

Cooke *et al* noted the importance of altered condylar angle as a major contributor to varus deformity, and they questioned in their review the importance of the cause of varus angulations when considering pathogenesis and therapy for knee OA.¹⁴ Additionally, a comparison study between Saudi Arabian and Canadian cohorts by the same group found some differences in these angles based on ethnicity.⁹ Nagamine *et al* also found significant differences in these angles when comparing Japanese patients with those from the USA and France.¹⁰

These studies differ from ours in that they include in their comparison subjects with and without OA. Joint space narrowing due to tibiofemoral OA is likely to alter the individual angles of alignment. Some authors, including Cooke *et al*, attribute the change in condyle–plateau angle to loss in joint space.¹⁴ In his study of Canadian subjects, he found the mean anatomical axis angle in healthy subjects to be 20.97° . His angles were measured from full-length radiographs and are therefore difficult to compare directly; however, a study by Kraus *et al* has shown the difference in neutral alignment to be approximately 4° more valgus for anatomic axis compared with the mechanical axis measurements.¹⁵ Although

direct comparison of data between studies is problematic, using this correction factor the angle measured by Cooke *et al* becomes approximately 3°, placing the Canadian cohort squarely between our FOA and BOA cohorts.⁹ A correction factor for the other angles is not known. It is also possible that the differences in alignment between their Canadian OA and Saudi OA cohorts are related to baseline racial differences in alignment.⁹ Pre-morbid Saudi data were not reported.

Nagamine *et al* also included normal and OA subjects in their study, but comparison is possible between our cohorts and their controls.¹⁰ Their femoral angle and tibia angle angles are complementary angles (measured on the lateral side; ours on the medial side) to our condylar angle and tibial plateau angle respectively. Nagamine *et al*'s cohorts include Japanese, French and American subjects and their results show that the Caucasian (French and American) subjects had a slightly more varus femoral angle compared with the Japanese cohort, although statistical significance was not reported. This supports our findings with our Chinese cohort, and may indicate that Asian subjects have a trend to more valgus alignment compared with Caucasian subjects.

It is unclear what factors may contribute to these alignment differences. The most straightforward potential explanation is that there are genetically programmed differences on bone morphology. These may cause differences in the bowing bones themselves (femur or tibia vara). Another potential explanation could be behavioural factors. For example, in our study, the Beijing population is known to perform more squatting than the Framingham population. Bicycle riding is another behavioural activity that is likely to be disparate between the populations. Other as yet unrealised behavioural factors could also contribute to the differences.

There are several limitations in our study. The BOA cohort was of a slightly older age than the FOA cohort. To our knowledge, there is no known association between age and knee alignment, and adjusting for age in our study did not significantly change the results. The FOA cohort had a higher BMI, but adjusting for BMI did not significantly change our results.

In addition, our alignment measures were taken from a short film. The measurement of mechanical axis is difficult, as it requires a full-length radiograph, and two studies showed a high correlation between data obtained from mechanical axis and anatomic axis measurements.¹⁵¹⁶ This obviates the need for the cumbersome full-length radiographs in exchange for the more commonly obtained, standard AP knee film.

It is also possible that the alignment differences observed are an early manifestation of disease that is present even before the presence of joint space narrowing (required for K&L 2) or even before any disease can be observed by *x*-ray. Further this is a cross-sectional analysis and any relation that differences in alignment could contribute to differences between these samples in the pattern of compartment-specific knee OA need to be further examined in longitudinal samples. No firm conclusions can be drawn from this cross-sectional study.

When compared with Caucasian knees, Chinese knees have a more valgus alignment of the distal femur. This would serve to shift the mechanical loading towards the lateral compartment, and provide one potential explanation for the higher prevalence of LTF OA among Chinese. Examinations of racial and ethnic differences in knee alignment combined with epidemiological data about patterns of OA are important to advancing our understanding of the aetiopathogenesis of OA. We suggest that comprehensive measurements, such as those used in this study, provide more useful information regarding alignment than simply measuring the anatomic or mechanical axis as has been done in most

previous studies. Future work in this area should focus on the longitudinal measurements of these angles and their relationship to the development of OA.

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Figure 1.

Drawing of a typical varus knee. (1) Femoral anatomic axis line. (2) Tibial anatomic axis line. (3) Condylar line. (4) Tibial plateau line. (a) Anatomic axis angle. (b) Condylar angle. (c) Tibial plateau angle. (d) Condylar–plateau angle.

Figure 2. Distribution of the anatomic axis angle in the Framingham Osteoarthritis Study (FOA) and Beijing Osteoarthritis Study (BOA) cohorts (unadjusted).

Table 1

Characteristics of FOA and BOA subjects by sex

	Women		Men	
	BOA n = 173	FOA n = 134	BOA n = 166	FOA n = 97
Age (SD)	66.0 (4.9)	63.6 (3.6) [†]	67.1 (5.2)	63.8 (3.9) [†]
BMI (SD)	25.0 (3.9)	25.9 (3.9)	24.9 (3.2)	27.7 (3.9) [†]
K&L = 0, N of knees (%)	314 (90.8)	248 (92.5)	291 (87.7)	175 (90.2)
K&L = 1, N of knees (%)	32 (9.2)	20 (7.5)	41 (12.4)	19 (9.8)

FOA, Framingham Osteoarthritis Study; BOA, Beijing Osteoarthritis Study; BMI, body mass index; K&L, Kellgren & Lawrence (grade).

*For the angles, negative numbers represent a varus direction and positive numbers represent valgus.

[†]Two-tailed p<0.001.

Table 2
Mean and mean differences of knee angles in Beijing and Framingham subjects by sex

	Women			Men			Total		
	BOA n = 173	FOA n = 134	Difference (p value)	BOA n = 166	FOA n = 97	Difference (p value)	BOA n = 339	FOA n = 231	Difference (p value)
Anatomic axis angle *	3.85	1.84	2.01 (<0.001)	4.79	3.44	1.35 (0.01)	4.32	2.59	1.73 (<0.001)
Condylar angle *	6.07	4.38	1.69 (<0.001)	6.36	6.21	0.15 (0.71)	6.25	5.16	0.6 (<0.001)
Plateau angle *	-1.64	-1.57	0.07 (0.63)	-1.30	-1.50	0.20 (0.21)	-1.62	-1.51	0.11 (0.82)
Condylar-plateau angle *	-0.69	-0.91	0.22 (0.09)	-0.45	-1.25	0.80 (<0.001)	-0.58	-1.03	0.45 (<0.001)

FOA, Framingham Osteoarthritis Study; BOA, Beijing Osteoarthritis Study.

Adjusted for age, body mass index.

* For the angles, negative numbers represent a varus direction and positive numbers represent valgus.