



## Effective measurement of knee alignment using AP knee radiographs

Alexandra N. Colebatch<sup>a,\*</sup>, Deborah J. Hart<sup>b</sup>, Guangju Zhai<sup>b</sup>, F.M. Williams<sup>b</sup>,  
Tim D. Spector<sup>b</sup>, Nigel K. Arden<sup>a</sup>

<sup>a</sup> MRC Epidemiology Resource Centre, University of Southampton, Southampton, United Kingdom

<sup>b</sup> Twin Research and Genetic Epidemiology Unit, St Thomas' Hospital, London, United Kingdom

### ARTICLE INFO

#### Article history:

Received 4 April 2008

Received in revised form 23 July 2008

Accepted 24 July 2008

#### Keywords:

Knee osteoarthritis

Alignment

Knee radiograph

Epidemiology

### ABSTRACT

The gold standard for measuring knee alignment is mechanical axis determined using full-limb radiographs (FLR). Measurement of joint alignment using antero-posterior (AP) knee radiographs is more accessible, economical and involves less radiation exposure to the patient compared with using full-limb radiographs. The aim of this study was to compare and assess the reproducibility of knee joint axial alignment on full-limb radiographs and conventional AP knee radiographs.

Knee alignment was measured in 40 subjects (80 knees) from the TwinsUK registry. Measurement of mechanical knee alignment was from FLR, and anatomic knee alignment from weight-bearing AP knee radiographs. Reproducibility was assessed by intra-class correlation coefficients and kappa statistics.

Reproducibility of knee alignment for both methods was good, with intra-observer ICC's of 0.99 for both FLR and AP radiographs. The mean alignment angle on FLR was 178.9° (SD 2.1, range 173–183°), and 179.0° (SD 2.1, range 173–185°) on AP films. 58.8% of knees on FLR and 66.3% on AP films were of varus alignment. Good correlations were seen between results for FLR and AP radiographs, with ICC ranging from 0.87–0.92 for left and right knees, and kappa statistics of 0.65–0.74.

Standard AP knee radiographs can be used to measure knee alignment with good reproducibility, and provide comparable results to those obtained from FLR. This will facilitate measurement of knee alignment in existing cohort studies to assess malalignment as a risk factor of incident OA, and in clinical practice.

© 2008 Elsevier B.V. All rights reserved.

### 1. Introduction

Osteoarthritis (OA), the most common form of arthritis affecting Western populations, is particularly common at weight-bearing joints such as the knee. More than 30% of people over 65 years of age have radiographic evidence of knee OA and around a third of these experience knee pain [1]. However, there is only a modest correlation between these features [2]. This analysis demonstrated Kellgren and Lawrence (K and L) radiographic grades of knee OA of 2 and over in 3.7% of the study group, but only 47% of these reported knee pain. Of subjects reporting knee pain, only 15% had such radiographic evidence of knee OA [2].

Knee alignment is a major determinant of load distribution through the knee, and is thought to play a role in disease progression of OA, both radiographically and symptomatically [3]. In primary knee OA, it has been shown that varus alignment increases the risk of medial OA progression, and valgus alignment increases the risk of lateral OA progression, with the severity of malalignment predicting the decline in physical function [3]. Malalignment of greater than 5° in

either varus or valgus direction has been shown to be associated with more functional decline compared with knees with less malalignment [3]. There is conflicting information, however, as to whether malalignment predicts disease incidence in the general population. The recent study by Brouwer et al. [4] showed that increasing varus malalignment is associated with progression of knee OA, as well as with development of knee OA, although this finding was only seen in overweight persons. Hunter et al. [5] recently found no association between knee alignment and incidence of knee OA.

The gold standard method of measuring knee alignment is the mechanical axis of the lower limb, using weight-bearing full-limb radiographs. This technique is however, time consuming, requires special equipment, and involves significant radiation exposure. More importantly, this method cannot be applied to many of the existing large population-based cohort studies with a long duration of follow-up, which are ideal to explore risk factors for imminent disease, as they have obtained standard AP radiographs as opposed to FLR. It is therefore of value to establish if this technique of measuring anatomical axis from limited AP knee radiographs is a valid measure of knee alignment in the general population at risk of developing incident knee OA.

As there are therefore several potential advantages to using AP knee radiographs to measure knee alignment, this study aims to assess reproducibility of lower limb axial alignment using mechanical

\* Corresponding author. MRC Epidemiology Resource Centre, University of Southampton, Southampton General Hospital, Tremona Road, Southampton SO16 6YD, United Kingdom. Tel.: +44 7718 207347; fax: +44 238070 4021.

E-mail address: a\_colebatch@hotmail.com (A.N. Colebatch).

axis on FLR, and knee alignment using anatomical axis on AP knee radiographs. The objective of this study is to demonstrate that AP radiographs are a reliable method of measuring knee alignment.

## 2. Method

### 2.1. Subjects

Knee alignment was measured in 40 female subjects (80 knees), recruited at random from the St Thomas' TwinsUK Adult Twin Registry, St Thomas' Hospital. Ethical approval for the study was obtained from the Guys and St Thomas' Trust.

### 2.2. Radiographs

Full-limb radiographs were obtained using a dedicated 51 by 14 inch graduated grid cassette, which included the full limb of tall subjects. The subject stood without footwear, with tibial tubercles facing forward with the X-ray beam centred at the knee at a distance of 8 ft. A setting of 100–300 mA-s and a kilo voltage of 80–90 were used depending on limb size and tissue characteristics.

The AP, weight-bearing, short knee X-ray was obtained with the patient standing with the back of their knees in contact with the vertical cassette, and the central beam centred 2.5 cm below the apex of the patella with a film to focus distance of 100 cm. Both knees were radiographed together. The patient was asked to stand with their feet slightly externally rotated, so that the angle between the feet was approximately 15°. All radiographs were obtained with the same technique for each subject.

### 2.3. Measurement of angles

Angles from both types of film were measured as described below using a standard plastic 30 cm goniometer, and recorded in degrees  $\pm 180^\circ$  (neutral). Angles greater than  $180^\circ$  represent a valgus alignment, and angles lesser than  $180^\circ$  a varus alignment.

Mechanical alignment was measured using the FLR by measuring the angle in degrees subtended by one line connecting the centre of the femoral head with the middle of the knee (midpoint of the tibial spines), and the other line connecting the middle of the surface of the talus with the middle of the knee (Fig. 1A) [3].

Anatomical alignment is measured from the AP knee radiographs as shown in Fig. 1B. A dot is placed at the midpoint of the tibial spines. The femoral anatomical axis is then found by drawing a line from the midpoint of the tibial spines to a point 10 cm above the tibial spines, midway between the medial and lateral femoral cortical bone surfaces. The tibial anatomical axis is found by drawing a line from the midpoint of the tibial spines to a point 10 cm below the tibial spines, midway between the medial and lateral cortical bone surfaces. The medial angle of the intersection of the axes is then measured by goniometer, with measurements recorded as either  $>180^\circ$  or  $<180^\circ$  depending on valgus or varus malalignment [6].

Radiographic evidence of OA was also recorded, according to K and L grade.

Reproducibility was performed on 20 subjects (i.e. 40 knees), by two readers (DH and LS for FLR, and DH and GZ for AP films), to assess inter- and intra-observer reproducibility. The readers, who were all experienced in measuring knee alignment, were a Professor of Rheumatology (LS), an experienced researcher with training in occupational therapy, epidemiology and joint examination (DH), and a physician with training in epidemiology and knee alignment (GZ). Reproducibility was blinded, with all measurements carried out with no knowledge of prior results, and all markings were erased for each reader.

### 2.4. Statistical analysis

Mean and standard deviation angles for each technique were computed. The angles obtained using both techniques were compared using a student's *t*-test. The percentage of knees in varus, valgus or neutral were also calculated, in addition to the percentage of knees with more than  $2^\circ$  of malalignment. This empirical cutoff was used as

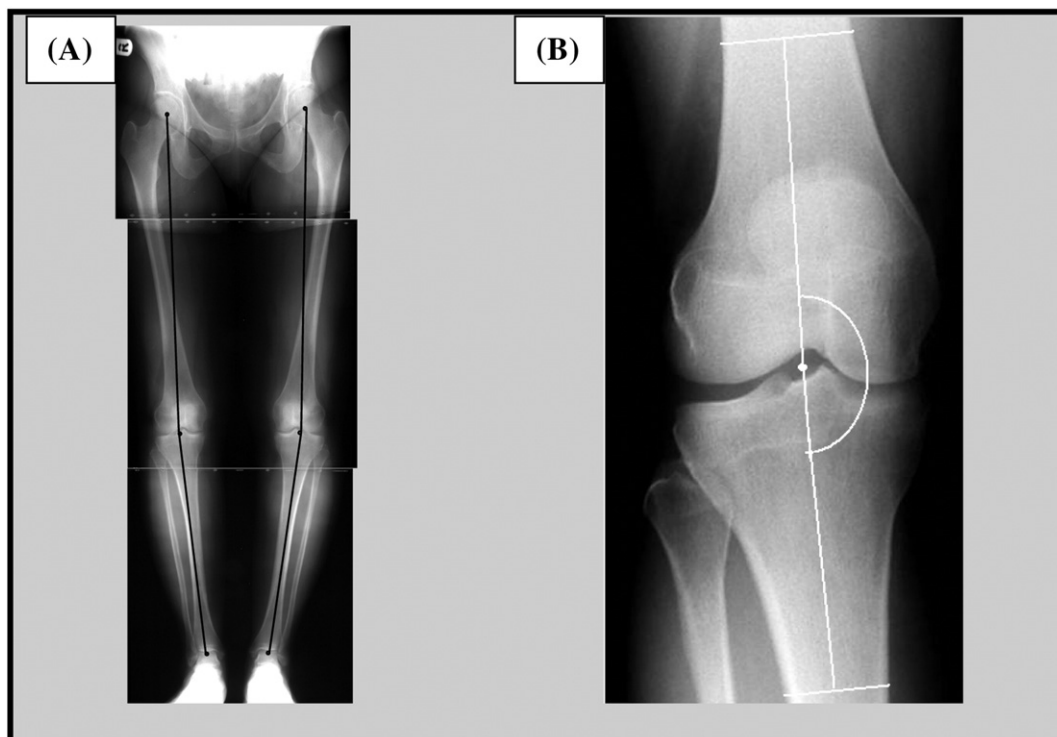


Fig. 1. Measurement technique for knee alignment from (A) FLR and (B) AP knee radiographs.

**Table 1**  
Comparison of mean angle and alignment between full-limb and AP knee radiographs

	Full-limb radiograph	AP knee radiograph
Angle ° (mean (SD))	178.9 (2.1)	179.0 (2.1)
Alignment (no./%)		
Neutral	23 (28.8%)	15 (18.8%)
Varus	47 (58.8%)	53 (66.3%)
Valgus	10 (12.5%)	12 (15.0%)
>2° malalignment (no./%)	30 (37.5%)	18 (22.5%)

although 5° of malalignment has been shown to be associated with greater functional decline, few patients with such malalignment were identified in this study (see Results). We calculated inter- and intra-observer agreement for all films using intra-class correlation coefficient (ICC) for continuous variables. The kappa statistic was used for categorical variables (normal, varus, valgus alignment).

This study had the statistical power to detect a difference of 1.28°, with 80% power at the 5% significance level.

### 3. Results

Knee alignment was measured in 40 female patients with a mean age ( $\pm$ SD) of  $53 \pm 8$  years, and mean BMI ( $\pm$ SD) of  $26.0 \pm 5.2$  kg/m<sup>2</sup>. None of the participants had radiographic evidence of OA (K and L grade  $\geq 2$ ).

The mean reading time for knee alignment using full-limb radiographs was 3 min, with inter-observer agreement of  $r=0.98$  ( $p<0.001$ ) and intra-observer agreement of  $r=0.99$  ( $p=0.001$ ). For AP knee radiographs, the mean reading time was only 1 min, with inter-observer agreement for alignment of  $r=0.99$  ( $p<0.001$ ) and intra-observer agreement of  $0.99$  ( $<0.001$ ).

The range of angle of malalignment in either knee was 173–183° on FLR, and 173–185° on AP films. The mean angle for FLR (SD) was 178.9° (2.1) and 179.0° (2.1) for AP films, which was not a statistically significant difference ( $p=0.57$ ). 58.8% of knees on FLR and 66.3% on AP films were of varus alignment (Table 1). Correlation between FLR and AP alignment ranged from  $r=0.87$ – $0.92$  for left and right knees, and overall  $r=0.81$  for both knees.

When categorising radiographs as neutral, valgus or varus, the kappa for AP knee radiographs compared to FLR was 0.74. When all radiographs categorised as  $>2^\circ$  or  $\leq 2^\circ$  of malalignment were analysed, the kappa for AP results versus FLR was 0.65 (both sides). These results therefore show substantial agreement, as scored by Landis and Koch [7]. There were not enough knees with  $>5^\circ$  of malalignment to assess this threshold.

On classification of the radiographs into neutral, varus or valgus the major source of misclassification occurred when alignment was coded as neutral on full-limb radiograph and varus on AP in 8/80 (10%). However in all these cases malalignment was only 1°. In only one case (1.2%) was malalignment graded as varus on one film and valgus on another. However, when classifying the radiographs with more than 2° malalignment all misclassification (15%) occurred where an angle of greater than 2° was measured on FLR but not on the AP knee film.

### 4. Discussion

This study demonstrated that AP knee radiographs are a reliable, but less time consuming, method of measuring knee alignment. The gold standard for measuring knee alignment is with weight-bearing full-limb radiographs, allowing calculation of the mechanical axis of the lower limb. This investigation is not routinely performed on patients in the clinical setting, and results in greater cost and inconvenience. Full-limb radiographs involve exposure of the pelvis to radiation, with effective radiation from one film at 73-fold higher than an AP knee radiograph [8]. This study suggests that AP knee radiographs may be used for measuring knee alignment by anatomical axis, which are safer and more readily available in clinical practice.

Previous studies have addressed the association of mechanical and anatomical knee alignment. Hinman et al. [6] examined this association in patients with symptomatic, medial knee OA using FLR's for both measurements and demonstrated a good correlation ( $r=0.88$ ,  $p<0.001$ ). A further study used FLR's and fixed flexion posteroanterior (PA) knee radiographs to assess knee alignment from mechanical and anatomical axis in subjects with radiographic OA [9]. This study did demonstrate significant correlation between these

techniques (anatomical and mechanical axis correlation,  $r=0.65$ ,  $p<0.0001$ ; fixed flexion knee radiograph and mechanical axis correlation,  $r=0.75$ ,  $p<0.0001$ ), but also identified an angle offset for the anatomical axis from the mechanical axis. Issa et al. [10] used semi-flexed knee radiographs and FLR to obtain knee alignment measurements in their study, which also addressed the relationship of knee alignment to OA disease features seen on magnetic resonance imaging. The authors also demonstrated a strong correlation between knee alignment from the FLR's with that from knee radiographs ( $r=0.86$ ; 95% confidence interval 0.81, 0.90).

Knee alignment predicts progression in knee OA, however there is conflicting data describing if it predicts incidence. Although Sharma et al. [3] and Brouwer et al. [4] demonstrated a relationship between these, Hunter et al. [5] found no such relationship in their study. In order to clarify this question, further large cohort studies with long-term follow-up data is required. Cohorts with such data available have previously used AP extended, weight-bearing knee radiographs as part of the study. The studies described above have validated the technique for measuring knee alignment, but have all been in patients with existing knee OA, and not used AP extended, weight-bearing knee radiographs. This radiographic approach has therefore not been validated as a risk factor of incidence of knee OA.

Previous studies into knee alignment have described an offset angle between the anatomical and mechanical axes [9,10]. These studies were performed using fixed flexion [9] and semi-flexed [10] knee radiographs. Kraus et al. [9] identified a mean offset for the anatomical axis of 4.21° valgus from the mechanical axis (3.5° in women) using fixed flexion posteroanterior (PA) knee radiographs and FLR's respectively, whereas Issa et al. [10] found the alignment on semi-flexed knee radiographs to be 3.4° more valgus than the FLR (3.0° in women). Our study, which used fully extended knee radiographs, found no evidence of an offset angle either in terms of the mean alignment or those classified as valgus. This has a major implication to applying offset angles to older cohort studies that have also used fully extended AP knee radiographs. For this reason, we would be cautious about extrapolating these results to patients with significant fixed flexion deformities of the knee.

A limitation of this study is found in the method of pinpointing the centre of the knee in order to measure knee alignment in both methods. This can be complicated as the tibial spines can be difficult to identify in patients with OA due to knee deformity and overlying chondrocalcinosis. Although none of the subjects included in this study had radiographic evidence of OA, this limitation should be taken into account in future studies. Although the subjects in this study were all female, there is no rationale to suggest that these results are not applicable to men. Ideally, this study should be repeated in a similar, male population.

Our data demonstrates that measuring knee alignment from the AP weight-bearing radiograph is reproducible, and correlates with knee alignment from the full-limb radiograph. This is the first study to assess the validity of a standard AP film for measuring knee alignment in patients without OA. The method for measuring knee alignment from AP knee radiographs is much less time consuming compared with the time taken to read full-limb radiographs, which is of benefit both in clinical and research settings. This is of particular importance as many of the existing large population cohort studies, which involve patients with normal knees and those with a background of OA, have examined knee OA using AP knee radiographs. This data would suggest that the AP technique used would be useful for assessing malalignment in these cohorts.

### Acknowledgement

The authors are grateful to Professor Leena Sharma for her input and critical evaluation of this article.

## References

- [1] Cooper C. Epidemiology of osteoarthritis. In: Klippel JH, Dieppe PA, editors. *Rheumatology*. 2nd ed. London: Mosby; 1998. p. 1–20.
- [2] Hannan MT, Felson DT, Pincus T. Analysis of the discordance between radiographic changes and knee pain in osteoarthritis of the knee. *J Rheumatol* 2000;27:1513–7.
- [3] Sharma L, Song J, Felson DT, Cahue S, Shamiyeh E, Dunlop DD. The role of knee alignment in disease progression and functional decline in knee osteoarthritis. *JAMA* 2001;286:188–95.
- [4] Brouwer GM, van Tol AW, Bergink AP, Belo JN, Bernsen RMD, Reijman M, et al. Association between valgus and varus alignment and the development and progression of radiographic osteoarthritis of the knee. *Arthritis Rheum* 2007;56:1204–11.
- [5] Hunter DJ, Niu J, Felson DT, Harvey WF, Gross KD, McCree P, et al. Knee alignment does not predict incident osteoarthritis: the Framingham Osteoarthritis Study. *Arthritis Rheum* 2007;56:1212–8.
- [6] Hinman R, May R, Crossley K. Is there an alternative to the full-leg radiograph for determining knee joint alignment in osteoarthritis? *Arthritis Rheum* 2006;55:306–13.
- [7] Landis JR, Koch GG. An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics* 1977;33:363–74.
- [8] Hart D, Wall BF. Radiation exposure of the UK population from medical and dental X-ray examinations. Document NRPB-R289. Chilton, UK: National Radiological Protection Board; 2002.
- [9] Kraus V, Vail T, Worrell McDaniel GA. Comparative assessment of alignment angle of the knee by radiographic and physical examination methods. *Arthritis Rheum* 2005;52:1730–5.
- [10] Issa S, Dunlop D, Chang A, Song J, Prasad P, Guermazi A, et al. Full-limb and knee radiography assessments of varus–valgus alignment and their relationship to osteoarthritis disease features by magnetic resonance imaging. *Arthritis Rheum* 2007;57:398–406.