Using the Anatomical Axis as an Alternative to the Mechanical Axis to Assess Knee Alignment

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abstract

The treatment of knee osteoarthritis and the preparation for total knee arthroplasty require repetitive imaging to guide preoperative planning and operative technique. Full-length standing anteroposterior images are the gold standard in assessing the alignment of the limb via the measurement of the mechanical axis of the knee. The anatomical axis can be obtained from a more limited image of the knee, and as such is less expensive and exposes the patient to less ionizing radiation. The objective of this cross-sectional prospective study was to examine the extent to which the anatomical axis measured on a fixed-flexed posteroanterior (Rosenberg view) radiograph correlates with the mechanical axis. The data of 209 total knee arthroplasty radiographs were analyzed to compare the preoperative correlation between the mechanical and anatomical axis. The anatomical axis correlated with the mechanical axis when it was measured from both the standing full-length anteroposterior radiograph and from a fixed-flexed posteroanterior radiograph. Using an angle of offset found from linear regression, these correlations become closer. Body mass index and Kellgren-Lawrence grade were not found to have a significant effect. It is the conclusion of this study that the anatomical axis, as measured from a limited knee radiography, may serve as a plausible estimate of the mechanical axis when done with a neutral angle of offset, and that offset angle depends on gender and the imaging technique used to determine the anatomical axis. [Orthopedics. 2015; 38(12):e1115-e1120.]
Osteoarthritis is the most common cause of knee pain in individuals 50 years or older. Symptomatic knee osteoarthritis is strongly correlated to obesity and aging. As the population in the United States continues to age and the prevalence of obesity increases, it is understandable that symptomatic knee osteoarthritis has also increased in the past 20 years. This is of significant clinical and financial importance because the assessment and treatment of osteoarthritis requires repetitive imaging to guide treatment, preoperative evaluation and planning, and follow-up care.

The gold standard for the evaluation of the mechanical axis of the knee is a standing full-length lower extremity anteroposterior (AP) radiograph. Varus or valgus malalignment are strong predictors for functional decline of those with osteoarthritis. Drawbacks to obtaining a standing full-length AP radiograph include cost, ionizing radiation to the pelvis, availability, funding from national health care systems, and the labor required for extrapolation of the femoral and tibial mechanical axes using bony landmarks. It has been postulated that using the anatomical axis from a limited knee radiograph may be an alternative, less expensive method to predict the mechanical axis of the knee.

The authors’ hypothesis is that the anatomical axis, measured from either a standing full-length AP or fixed-flexed posteroanterior (PA) (Rosenberg view) radiograph of the knee, can be accurately correlated with the mechanical axis measured from a full-length AP radiograph. The secondary hypothesis is that gender, body mass index (BMI), and Kellgren-Lawrence (KL) grade will not significantly affect the correlation between the anatomical and mechanical axis.

**Materials and Methods**

This study received institutional review board approval and was compliant with the Health Insurance Portability and Accountability Act. A cross-sectional prospective study was conducted using a joint replacement database from 209 consecutive primary total knee arthroplasties (TKAs) at a university medical center. Institutional review board approval was obtained, and informed consent was not deemed necessary by the institutional review board.

Inclusion criteria included complete preoperative standing full-length AP and preoperative standing fixed-flexed PA (Rosenberg view) radiographs. Imaging and anatomy that allowed for appropriate visualization of the required landmarks for measurement were required to measure the anatomical and mechanical knee axis. Seventy-four patients did not have adequate imaging and were excluded. Patients were also excluded if significant bony deformity existed that prevented visualization of the anatomical landmarks for measurement (2 patients) or if additional retained hardware obstructed visualization and prevented adequate measurements (6 patients).

One hundred and twenty-seven TKAs met the inclusion criteria. For the purposes of this study, 180° was considered neutral knee alignment and negative values (<180°) were assigned to varus alignment and positive values (>180°) were assigned to valgus alignment.

Preoperative fixed-flexed PA digital images of the knee and preoperative standing full-length AP digital images of the lower extremities were obtained using Fugifilm computed radiography system (Fugifilm USA, Valhalla, New York) using standard protocol. Images were processed using Fugifilm Automatic Image Stitching Software. The digital images were viewed on AGFA Impax PACS software (AGFA, Morsel, Belgium) and measurements obtained using a digital cursor.

The mechanical axis was measured by drawing 2 intersecting lines on the radiograph, as was demonstrated by Cooke et al. A line is drawn from the center of the femoral head through the intercondylar notch of the distal femur. This intersects with a second line extended from the center of the tibial plafond through the center of the tibial plateau (Figure 1).

![Figure 1: Standing full-length anteroposterior radiograph showing the measurement of the hip-knee-ankle angle. The tibial and femoral mechanical axes are measured on the radiography, and the axis between them is the hip-knee-ankle angle.](image-url)
The measurement of the anatomical axis was performed as done by Kraus et al. A line is drawn from the center of the tibia through the tibial spines. The second line is drawn from the center of the femur through the trochlear groove. The origin of these lines is always 10 cm (proximal and distal) from the knee joint surfaces. The measurement of the angle formed by the intersection of the 2 lines is the anatomical axis. Using this technique, the measurement of the anatomical axis from the standing full-length AP radiograph required only a view 10-cm proximal and distal to the knee joint; as such, it was used to represent a limited AP radiograph of the knee on a patient standing upright. The anatomical measurement was also repeated for the fixed-flexed PA knee view (Figure 2).

To ensure accuracy of the individual who performed the radiographical measurements, a second individual measured each of the endpoints for a randomly selected group of 15 patients in the study. Neither of the 2 individuals (S.C.T., J.S.) who measured the radiographs was the primary surgeon. To determine the variability in the measurement, an intraclass correlation coefficient was determined to be greater than 0.85 for each of the endpoints. This demonstrates that there was a small amount of variability in measurements.

The preoperative mechanical axis as measured on a standing full-length AP radiograph (mechanical\textsubscript{AP} axis) was compared to the preoperative anatomical axis measured on that same radiograph (anatomical\textsubscript{AP} axis), as well as a preoperative fixed-flexed PA knee radiograph (anatomical\textsubscript{PA} axis). A comparison was also done between the 2 different measurements of the preoperative anatomical axis taken from the 2 different radiographic views. The role of gender, BMI, and preoperative KL grade was also assessed.

**Statistical Analysis**

Using Microsoft Office 2010 Excel (Microsoft Corp, Redmond, Washington) software calculations of averages and standard deviations were obtained, and a 2 sample paired \( t \)-test was executed giving the associated \( P \) value for each of the different categories. Also using this software, the offset of the anatomical and mechanical axes was determined using linear regression.

**Results**

Seventy-seven (60.1%) of the 127 TKAs in the study cohort were for women. Average age was 67.9 years (range, 34-90 years), and patients had an average BMI of 29.9 kg/m\(^2\) (range, 17.2-42.3 kg/m\(^2\)). Average preoperative KL grade was 3.2 (SD, 0.79) (Table 1). As seen in Table 2, the average preoperative mechanical axis using the standing full-length AP radiograph (mechanical\textsubscript{AP} axis) was 176.0° (SD, 8.9°). The average preoperative anatomical axis was 180.2° (SD, 6.9°) for the standing full-length AP radiograph (anatomical\textsubscript{AP} axis) and 181.3° (SD, 7.7°) for the fixed-flexed PA radiograph (anatomical\textsubscript{PA} axis).

Using linear regression analysis, the relationship between the mechanical\textsubscript{AP} axis and the anatomical\textsubscript{AP} axis was determined. Per the analysis, the relationship is as follows: mechanical\textsubscript{AP} axis=1.14 (anatomical\textsubscript{AP} axis)–30.0. This relationship has an associated \( R^2 \) value of 0.80. The linear regression plot is seen in Figure 3. The correlation of the 2 measurements in women (\( R^2=0.80 \)) was similar to that of men (\( R^2=0.75 \)).

### Table 1

**Patient Demographics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Whole Sample</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total knee arthroplasty, No.</td>
<td>127</td>
<td>77</td>
<td>50</td>
</tr>
<tr>
<td>Age, mean±SD, y</td>
<td>67.9±10.5</td>
<td>68.5±10.0</td>
<td>67.0±11.6</td>
</tr>
<tr>
<td>Body mass index, mean±SD, kg/m(^2)</td>
<td>29.9±5.0</td>
<td>30.0±5.5</td>
<td>29.5±4.0</td>
</tr>
<tr>
<td>Preoperative KL grade, mean±SD</td>
<td>3.2±0.79</td>
<td>3.1±0.84</td>
<td>3.3±0.68</td>
</tr>
</tbody>
</table>

*Abbreviation: KL, Kellgren-Lawrence.*

### Table 2

**Measurement Results Grouped by Sex**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Whole Sample</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical\textsubscript{AP} axis</td>
<td>176.0°±8.9°</td>
<td>177.5°±9.1°</td>
<td>173.8°±8.2°</td>
</tr>
<tr>
<td>Anatomical\textsubscript{AP} axis</td>
<td>180.2°±6.9°</td>
<td>181.1°±7.2°</td>
<td>178.9°±6.1°</td>
</tr>
<tr>
<td>Anatomical\textsubscript{PA} axis</td>
<td>181.3°±7.7°</td>
<td>182.0°±8.2°</td>
<td>180.2°±6.6°</td>
</tr>
</tbody>
</table>

*Abbreviations: AP, anteroposterior; PA, posteroanterior.*
The mechanical_\text{AP} axis was also compared to the anatomical_\text{PA} axis (Figure 4). The analysis demonstrated the following relationship: mechanical_\text{AP} axis=\{0.93 \ (anatomical_\text{PA} axis)\}+7.43. The \( R^2 \) value for the analysis is 0.65. The comparison of measurements in women (\( R^2 = 0.67 \)) was similar to that of men (\( R^2 = 0.789 \)).

The anatomical_\text{AP} axis was compared to the anatomical_\text{PA} axis (Figure 5). The correlation between the 2 demonstrated an \( R^2 \) value of 0.703. The relationship between the 2 was found to be: anatomical_\text{AP} axis=\{0.75 \ (anatomical_\text{PA} axis)\}+44.06.

As Kraus et al\(^7\) reported, the neutral (offset) angle was determined by finding the angle of the anatomical axis that corresponds to 180° of the mechanical axis. This was done by extrapolation from the linear regression models (Figures 3-5). Using the mechanical_\text{AP} axis as neutral, the average angle of offset was 183.68° (3.68°) (\( R^2 = 0.789 \)) for the anatomical_\text{AP} axis and 185.56° (5.56°) (\( R^2 = 0.651 \)) for the anatomical_\text{PA} axis. The numbers in parentheses after the angle of offset signify the total difference between the mechanical_\text{AP} axis and the other measurement to which it is being compared. The results are presented in Table 3.

To minimize the possibility of underlying confounding factors, aside from gender, the data were separated by BMI and preoperative KL grade. Those who had a BMI greater than the average patient population of this study (>29.9, BMI\(_H\)) were placed into 1 group and compared with those having a BMI less than the average patient population (≤29.9, BMI\(_L\)). The \( R^2 \) values for the BMI\(_H\) group were 0.79 for the mechanical_\text{AP} axis vs the anatomical_\text{AP} axis and 0.55 for the mechanical_\text{AP} axis vs the anatomical_\text{PA} axis. The \( R^2 \) values for the BMI\(_L\) group were 0.57 and 0.64 for the same respective comparisons. For the BMI\(_H\) group, the neutral value was 183.60° (3.60°) for the mechanical_\text{AP} axis vs anatomical_\text{AP} axis and 185.56° (5.56°) for the mechanical_\text{AP} axis vs anatomical_\text{PA} axis comparisons. The neutral value for the BMI\(_L\) group was 183.69° (3.69°) and 185.74° (5.74°) for the same respective comparisons.

Those with a KL grade >2 (KL\(_H\)) were placed into a group separate from those with a KL grade ≤2 (KL\(_L\)). The \( R^2 \) values for the measurements of the KL\(_L\) group were 0.57 for the mechanical_\text{AP} axis vs anatomical_\text{AP} axis and 0.64 for the mechanical_\text{AP} axis vs anatomical_\text{PA} axis. For the KL\(_H\) group, the \( R^2 \) values were 0.80 for the mechanical_\text{AP} axis vs anatomical_\text{AP} axis and 0.68 for the mechanical_\text{AP} axis vs anatomical_\text{PA} axis. The neutral value was 183.75° (3.75°) for both KL groups for the mechanical_\text{AP} vs anatomical_\text{AP} axis comparison. The neutral angle was 185.71° (5.71°) and 185.63° (5.63°) for the mechanical_\text{AP} axis vs anatomical_\text{PA} axis comparison for the KL\(_L\) and KL\(_H\) groups, respectively.

**DISCUSSION**

When preparing for TKA surgery and assessing alignment of the knee, the current gold standard is the standing full-length AP radiograph. This study set to provide evidence that the use of the anatomical axis, measured from a limited...
image of the knee joint, to assess the mechanical axis of the knee may be a suitable alternative to the mechanical axis measured on a standing full-length AP image. Although there was a statistically significant difference in all comparisons of mechanical vs anatomical axis measurements ($P<.0001$ in most assessments), a correlation could be made between the anatomical and mechanical axis. When the analysis included the entire cohort, the $R^2$ value was greater than 0.65 in all comparisons. This suggests that the linear regression model accounts for a large portion of the variability within the comparison of the 2 knee alignment measuring techniques (anatomical and mechanical). Thus, with the use of the neutral angle to account for the differences, the correlation becomes even more direct.

Others have investigated similar questions previously. Kraus et al\textsuperscript{7} used both full-length AP and fixed-flexed PA images to measure the anatomical axis and compare it to the mechanical axis preoperatively. It was found that the overall offset was 184.31° and 183.96° for the full-length AP (anatomical\textsubscript{AP} axis) and fixed-flexed PA (anatomical\textsubscript{PA} axis) images, respectively. These results are within 2° of the current study (183.68° and 185.56°, respectively). The results of the study by Kraus et al\textsuperscript{7} were also consistent with the current study in that the neutral offset angle is consistently greater in men compared to women. The neutral angle is always in the valgus direction in the current study, as it is in all other studies mentioned within this discussion. Although Kraus et al\textsuperscript{7} used those with KL grade >0 to discuss the risk of progression of osteoarthritis, the current study investigates the correlation of those who have already met TKA criteria. This expands the potential utility and indications of using a limited radiograph of the knee to estimate the mechanical axis in the context of preoperative planning.

Hinman et al\textsuperscript{6} and Colebatch et al\textsuperscript{8} each used a standing AP knee image to compare the anatomical with the mechanical axis. Although Hinman et al\textsuperscript{6} and Colebatch et al\textsuperscript{8} found a mean neutral offset of 180.8° and 180.1°, respectively, Chang et al\textsuperscript{10} suggested a varying offset dependent on sex and KL grade. These values varied from 183.2° for male patients with a KL grade of 0-1 to 187.3° for female patients with a KL grade of 3-4.\textsuperscript{10} The current study differed with the findings of Chang et al\textsuperscript{10} in that the neutral angle was found to be greater in men than women in the current study. In addition, with different KL grades, the neutral angle did not change significantly (never differed by more than 0.5°).

When the assessments of the 2 different anatomical axes were compared, they demonstrated a significant difference ($P=.0045$). The fixed-flexed position is often obtained over the standing AP radiograph of the knee due to their increased accuracy, specificity, and sensitivity in identifying major knee joint degeneration.\textsuperscript{12} However, in the current study, the correlation was closer when the mechanical\textsubscript{AP} axis was compared with the anatomical\textsubscript{AP} axis than when the mechanical\textsubscript{AP} axis was compared with the anatomical\textsubscript{PA} axis. This suggests that when obtaining imaging of the knee to assess alignment, a standing AP radiograph of the knee may be preferred to a fixed-flexed PA position (Rosenberg view). However, a clear correlation was seen in both assessments.

Using a larger population to standardize a neutral offset angle, it may be possible to accurately predict the mechanical axis from the anatomical axis obtained from an image looking only at the knee
joint with the patient in any standard position. The degree of error may be larger using a fixed-flexed image, as was demonstrated in the current study. When BMI was assessed in the current study, none of the neutral values differed by more than 0.5°. This suggests that BMI did not greatly affect any of the comparisons of anatomical to mechanical axis.

There are several limitations to this study. The errors associated with measuring the mechanical axis from full-length radiographs are well known. However, this technique remains the gold standard and has been shown to have acceptable reliability and reproducibility. Standing full-length AP radiographs were used for the measurement of limb alignment. It is possible that deformity other than that in the coronal plane may have had a role and gone unrecognized. Furthermore, when measuring the angles, identifying the pertinent landmarks was occasionally difficult. Digital manipulation of the contrast of the radiograph to compensate for over penetration of the lower extremities was done to assist in identifying these landmarks. As Petersen et al noted, the radiographic plate is sometimes not located precisely at joint line level. This can alter the anatomic axis measurement because it can shorten a segment on one side of the joint.

**CONCLUSION**

The anatomical axis may serve as a plausible estimate of the mechanical axis when done with a neutral angle of offset. This study agrees with those done previously suggesting that an angle of offset of 3.5° to 5.6° in the valgus direction closely correlates the anatomical with the mechanical axis of the knee. In addition, the anatomical axis measured from the standing AP radiograph has a closer correlation to the mechanical axis than the anatomical axis measured from the fixed-flexed PA knee image. Further study is necessary with a larger population to standardize a neutral offset angle to be used for conversion from anatomical to mechanical axis. This standardization should account for gender and imaging techniques used to obtain the anatomical angle, but this study does not support the need to account for preoperative KL grade or BMI.

**REFERENCES**


