Assessment of Lower Limb Alignment: Supine Fluoroscopy Compared with a Standing Full-Length Radiograph

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Assessment of Lower Limb Alignment: Supine Fluoroscopy Compared with a Standing Full-Length Radiograph

By Sanjeev Sabharwal, MD, and Caixia Zhao, MD

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**Background:** While a full-length standing anteroposterior radiograph of the lower extremity provides the best radiographic method for assessing limb alignment, other methods must be used intraoperatively. We have employed intraoperative fluoroscopy with use of an electrocautery cord to assess limb alignment in the supine patient.

**Methods:** We retrospectively compared the measurements of lower limb alignment that were obtained with use of supine intraoperative fluoroscopy with those that were obtained with use of a full-length standing anteroposterior radiograph of the lower extremity. A single examiner compared 102 sets of supine fluoroscopy images and full-length standing anteroposterior radiographs of the lower extremity to assess mechanical axis deviation and the joint line convergence angle. For the intraoperative fluoroscopic examination, an electrocautery cord was positioned overlying the center of the femoral head and the tibial plafond and an anteroposterior radiograph of the knee was made. The effect of age, gender, diagnosis, body mass index, pelvic height difference, joint line convergence angle, and the magnitude and direction of malalignment (varus or valgus) on the discrepancy in the observed mechanical axis deviation with use of the two methods was assessed.

**Results:** The mean absolute difference between the two techniques was 13.4 mm for the measurement of mechanical axis deviation (p < 0.0001) and 2.8° for the joint line convergence angle (p < 0.0001). The correlation coefficient (r) for the measurement of mechanical axis deviation with use of the two radiographic methods was 0.88. An increase in body mass index was associated with a greater magnitude of discrepancy in the measurement of mechanical axis deviation between the two techniques (p = 0.0014). Age, gender, pelvic height difference, and the direction of malalignment had no effect on the discrepancy in the measurement of mechanical axis deviation. Limbs with >2 cm of mechanical axis deviation and those with a joint line convergence angle of >3° on the standing radiograph were significantly more likely to have >10 mm of discrepancy in the measurement of mechanical axis deviation with use of the two imaging techniques (p < 0.005).

**Conclusions:** Intraoperative fluoroscopy with use of the electrocautery cord method is a useful tool for assessing lower limb alignment in patients with a normal body mass index and ≤2 cm of mechanical axis deviation and ≤3° of joint line convergence angle on the standing anteroposterior radiograph. However, the results obtained with fluoroscopy should be interpreted with caution in patients who are obese or who have substantial residual mechanical axis deviation or pathologic laxity of the knee joint.

**Level of Evidence:** Diagnostic Level II. See Instructions to Authors for a complete description of levels of evidence.
A full-length standing anteroposterior radiograph of the entire lower limb, centered at the knee, allows for a comprehensive analysis of the magnitude and source of limb malalignment as well as an assessment of limb-length discrepancy. This radiographic technique is reproducible and is more accurate than clinical methods for assessing frontal plane deformities of the lower limb. However, such an imaging study cannot be performed intraoperatively.

Although portable radiographs and recently introduced computer-assisted navigational tools are available, fluoroscopy remains a commonly used method to measure lower extremity alignment following operative fixation of long-bone fractures and osteotomies of the lower extremity. The fluoroscopic method involves the use of a taut electrocauterity (Bovie) cord that is extended from the center of the femoral head to the center of the tibial plafond at the ankle. A fluoroscopic anteroposterior image of the knee is then made, and the alignment of the cord in relation to the center of the knee joint is used to measure the mechanical axis deviation of the lower extremity. While this technique has been described previously, we are not aware of any studies that have evaluated its accuracy.

The purpose of the present study was to compare the intraoperative measurement of lower limb alignment on a supine fluoroscopic image with that on a full-length standing anteroposterior radiograph of the same extremity. Our hypothesis was that the supine fluoroscopic method would be comparable with the use of a standing long-leg radiograph of the entire lower extremity for the assessment of lower limb alignment.

Materials and Methods

After institutional review board approval, the database of a single surgeon (S.S.) was searched for operative procedures that had been performed at a single institution from July 1997 to October 2006. During the study period, 682 patients (759 limbs) underwent lower limb surgery consisting of a femoral or tibial osteotomy (237 limbs), an epiphyseodesis or hemi-epiphyseodesis (147 limbs), knee arthrography (twenty-four limbs), removal of internal fixation (173 limbs), or removal of external fixation with the patient under general anesthesia (178 limbs). From this group, ninety-nine patients (102 limbs) were excluded from the study because standing radiographs had been made in the presence of an overlying cast or external fixator (five limbs), because an anteroposterior radiograph of the knee joint had not been made with the patella centered over the femoral condyles (six limbs), because a change in limb alignment had been documented between the dates of the two radiographs (three limbs), or because the electrocautery cord or osseous landmarks could not be clearly visualized on the saved fluoroscopic images (five limbs). With these exclusions, eighty patients (102 limbs) became the subjects of the study (Table I).

Clinical records were reviewed for demographic information (age, gender, height, and weight), the primary diagnosis, and the surgical procedure that had been performed. Body mass index was calculated as the weight in kilograms divided by the square of the height in meters.

### Table I: Demographic Data

<table>
<thead>
<tr>
<th>Age</th>
<th>No. of Patients (N = 80)</th>
<th>No. of Limbs (N = 102)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤18 yr</td>
<td>70 (88%)</td>
<td>90 (88%)</td>
</tr>
<tr>
<td>&gt;18 yr</td>
<td>10 (13%)</td>
<td>12 (12%)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>48 (60%)</td>
<td>63 (62%)</td>
</tr>
<tr>
<td>Female</td>
<td>32 (40%)</td>
<td>39 (38%)</td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>36 (45%)</td>
<td>50 (49%)</td>
</tr>
<tr>
<td>Left</td>
<td>44 (55%)</td>
<td>52 (51%)</td>
</tr>
<tr>
<td>Body mass index*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤30</td>
<td>51 (65%)</td>
<td>60 (61%)</td>
</tr>
<tr>
<td>&gt;30</td>
<td>27 (35%)</td>
<td>39 (39%)</td>
</tr>
<tr>
<td>Primary diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limb deformity</td>
<td>57 (71%)</td>
<td>60 (59%)</td>
</tr>
<tr>
<td>Limb-length discrepancy</td>
<td>15 (19%)</td>
<td>18 (18%)</td>
</tr>
<tr>
<td>Healed fracture</td>
<td>8 (10%)</td>
<td>7 (7%)</td>
</tr>
<tr>
<td>(Unaffected contralateral limb†)</td>
<td>—</td>
<td>17 (17%)</td>
</tr>
<tr>
<td>Procedure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osteotomy</td>
<td>29 (36%)</td>
<td>31 (30%)</td>
</tr>
<tr>
<td>Epiphyseodesis</td>
<td>10 (13%)</td>
<td>12 (12%)</td>
</tr>
<tr>
<td>Removal of external fixation</td>
<td>25 (31%)</td>
<td>25 (25%)</td>
</tr>
<tr>
<td>Removal of internal fixation</td>
<td>4 (5%)</td>
<td>5 (5%)</td>
</tr>
<tr>
<td>Knee arthrography</td>
<td>8 (10%)</td>
<td>8 (8%)</td>
</tr>
<tr>
<td>Soft-tissue reconstruction</td>
<td>4 (5%)</td>
<td>4 (4%)</td>
</tr>
<tr>
<td>(Unaffected contralateral limb†)</td>
<td>—</td>
<td>17 (17%)</td>
</tr>
<tr>
<td>Timing of standing radiograph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperatively</td>
<td>46 (58%)</td>
<td>64 (63%)</td>
</tr>
<tr>
<td>Postoperatively</td>
<td>34 (43%)</td>
<td>38 (37%)</td>
</tr>
</tbody>
</table>

*Body mass index was not available for two patients (three limbs).
†In seventeen patients, the alignment of the unaffected, contralateral limb was also assessed with fluoroscopy.

Nineteen patients (nineteen limbs) were excluded from the study because standing radiographs had been made in the presence of an overlying cast or external fixator (five limbs), because an anteroposterior radiograph of the knee joint had not been made with the patella centered over the femoral condyles (six limbs), because a change in limb alignment had been documented between the dates of the two radiographs (three limbs), or because the electrocautery cord or osseous landmarks could not be clearly visualized on the saved fluoroscopic images (five limbs). With these exclusions, eighty patients (102 limbs) became the subjects of the study (Table I).
Blount disease. The remaining patients had either limb-length discrepancy without deformity or a healed fracture of the femoral or tibial shaft. Detailed demographic information regarding the distributions of age, gender, the side of involvement, body mass index, primary diagnosis, surgical intervention, and whether the standing radiograph was made before or after the fluoroscopic examination is presented in Table I. The average age at the time of surgery was 14.3 years (range, 3.5 to 44.5 years), and the average body mass index was 28.1 (range, 13.5 to 61.8). Because of missing height information, body mass index could not be calculated for two patients.

A standing anteroposterior radiograph of both lower extremities was made with the patient facing the radiographic tube and the patellae pointing anteriorly (Fig. 1). The patient was instructed to place full and equal weight on both lower extremities, without being assisted by any supportive device. An attempt was made to level the pelvis by placing an appropriately sized lift under the shorter limb. The standing radiograph was made preoperatively for forty-six patients (sixty-four limbs). In these patients, the intraoperative pre-correction limb alignment was measured with the electrocautery cord technique and was compared with the alignment on a standing radiograph made an average of thirty-two days (range, zero to 145 days) preoperatively.

In the other thirty-four patients (thirty-eight limbs) undergoing acute or gradual deformity correction, the intraoperative post-correction alignment was measured with the electrocautery cord technique and was compared with that on a standing anteroposterior radiograph made an average of eighty-eight days (range, two to 464 days) postoperatively. For patients undergoing gradual correction with use of distraction osteogenesis, post-osteotomy limb alignment was assessed intraoperatively following removal of the fixator and then was compared with that on the postoperative standing radiograph.

All fluoroscopic examinations were performed under the direct supervision of the senior author (S.S.). The patient was placed supine on a radiolucent table, with the patella of the affected limb pointed toward the ceiling. The entire lower extremity, including the ipsilateral hip, was included in the sterile field. The centers of the femoral head and tibial plafond were identified fluoroscopically, and one end of the electrocautery cord was placed over the image of each of these landmarks. Then, an anteroposterior view of the knee was recorded. No specific templates or detailed measurements were used to identify these landmarks intraoperatively. The three fluoroscopic images, centered over the hip, ankle, and knee joints (Figs 2-A, 2-B, and 2-C) were saved and were later transferred to a Picture Archiving and Communications System (PACS)
workstation (Centricity PACS 2.0; GE Medical Systems Information Technologies, Milwaukee, Wisconsin).

Radiographic analysis involved assessment of the mechanical axis deviation and joint line convergence angle on both imaging studies. For the standing anteroposterior radiograph, the mechanical axis deviation was calculated (in millimeters) as the distance from the center of the femoral condyles to the vertical line connecting the center of the femoral head to the center of the tibial plafond (Fig. 1). Medial deviation of the mechanical axis was denoted as varus alignment of the limb, and lateral deviation was denoted as valgus malalignment. For the fluoroscopic examination, the mechanical axis deviation was calculated as the distance of the electrocautery cord from the center of the knee joint in pixels (Fig. 2-C). In order to compare the measurements with use of the two imaging techniques, the mechanical axis deviation (MAD) that was calculated in pixels with use of fluoroscopy was converted to millimeters. This was accomplished by documenting the entire width of the distal femoral condyles just proximal to the level of the intercondylar notch on the fluoroscopic view of the knee (d) and standing radiographs (D) with use of the formula:

\[
\text{MAD on fluoroscopy (in mm)} = \frac{\text{MAD on fluoroscopy (pixels)} \times D (\text{mm})}{d (\text{pixels})}
\]

The average width of the distal part of the femur (D) was 73 mm (range, 42 to 97 mm). The joint line convergence angle was measured in degrees as the angle between the distal femoral and proximal tibial articular surfaces for both imaging techniques. If the apex of the joint line convergence angle was medial it was denoted as varus, and if it was lateral it was denoted as valgus. The pelvic height difference (P) was calculated in millimeters as the difference in the height of the iliac crests on the standing anteroposterior radiograph. The joint line convergence angle could not be calculated because of a previous knee arthrodesis in one patient (one limb) and because of poor-quality fluoroscopic images in three patients (three limbs).

All radiographic measurements were performed by a single examiner (S.S.) at the PACS workstation with use of a digital cursor. Intraobserver reliability for measuring the mechanical axis deviation and the joint line convergence angle was calculated with use of a randomized set of twenty pairs of imaging studies of standing radiographs and fluoroscopic images that were measured a few weeks apart. Intraobserver reliability was recorded with use of the criteria of Winer. Reliability was classified, according to the intraclass correlation coefficient, as absent to poor (0 to 0.24), low (0.25 to 0.49), fair to moderate (0.50 to 0.69), good (0.70 to 0.89), or excellent (0.90 to 1.0).

The differences in the measurements of mechanical axis deviation and the joint line convergence angle with use of the
standing anteroposterior radiograph and fluoroscopy were analyzed with use of the paired t test. The mean absolute difference and 95% confidence intervals were calculated for the measurement of mechanical axis deviation and the joint line convergence angle with use of the two radiographic studies. The correlation coefficient ($r$) and simple regression analysis were utilized to study the relationship between the standing anteroposterior radiograph and fluoroscopy for the measurement of mechanical axis deviation. The possible values of $r$ range from $-1$ to $+1$. Correlation was classified, on the basis of the absolute value of $r$ (positive or negative), as weak (0.10 to 0.29), moderate (0.30 to 0.49), strong (0.5 to 0.99), or perfect (1.0). The effect of multiple variables (age, gender, side, body mass index, primary diagnosis, pelvic height difference, direction of malalignment, whether the fluoroscopic examination was done before or after the standing radiograph was made, and the magnitude of mechanical axis deviation and joint line convergence angle on the standing radiograph) on the discrepancy in the measurement of mechanical axis deviation with use of the two imaging techniques was assessed with use of multiple linear regression analysis for the continuous variables (age, body mass index, pelvic height difference, and the magnitude of mechanical axis deviation and joint line convergence angle on the standing radiograph) and with use of multiple logistic regression analysis for the categorical variables (gender, side, direction of malalignment, diagnosis, and whether the fluoroscopic examination was done before or after the standing radiograph was made). The chi-square test was used to study the relationship of factors such as the primary diagnosis and the magnitude of mechanical axis deviation and joint line convergence angle (as measured on the standing radiograph) with the discrepancy in the measurement of mechanical axis deviation with use of the two imaging techniques. The difference in the measurements of mechanical axis deviation on the standing radiograph and with use of fluoroscopy was plotted against the average of the mechanical axis deviation measurements obtained with use of the two techniques for each limb, as suggested by Bland and Altman. All statistical analysis was done for the entire study population of 102 limbs in eighty patients. In order to minimize the effect of any confounding variables related to the twenty-two patients in whom both limbs were evaluated with fluoroscopy, only one of the two limbs was randomly selected and the statistical analysis (including calculation of the correlation coefficient [$r$] and the difference in the measurements of mechanical axis deviation and joint line convergence angle with use of the standing anteroposterior radiograph and fluoroscopy) was repeated for eighty limbs. The alpha level for all analyses was set at $p < 0.05$. 

Fig. 2-C
Results

The intraobserver reliability for the measurement of mechanical axis deviation was excellent for the standing radiograph (intraclass correlation coefficient, 0.99) as well as for fluoroscopy (intraclass correlation coefficient, 0.99). The intraobserver reliability for measurement of the joint line convergence angle was excellent for the standing radiograph (intraclass correlation coefficient, 0.93) and good for fluoroscopy (intraclass correlation coefficient, 0.83).

The mean mechanical axis deviation was 7.1 mm medial (range, 86 mm lateral to 126 mm medial) with use of the standing radiograph and 7.7 mm medial (range, 74 mm lateral to 136 mm medial) with use of fluoroscopy (p = 0.90). The mean joint line convergence angle was 1.8° medial (range, 9° lateral to 27° medial) with use of the standing radiograph and 2.5° medial (range, 3° lateral to 18° medial) with use of fluoroscopy (p = 0.25). For the entire study population, the mean absolute difference between the two techniques was 13.4 mm for the measurement of mechanical axis deviation (p < 0.0001) and 2.8° for the joint line convergence angle (p < 0.0001). The mean absolute difference between the two imaging techniques for the measurement of the joint line convergence angle was the same (2.8°) for the entire study population and for the subgroup of eighty limbs (p = 0.92).

The mean mechanical axis deviation was 8.9 mm medial (95% confidence interval, 2.1 mm lateral to 19.9 mm medial) for the patients for whom the standing radiograph was made before the fluoroscopic examination, compared with 3.9 mm (95% confidence interval, 3.0 mm lateral to 10.9 mm medial) for those for whom the standing radiograph was made after the fluoroscopic examination (p = 0.45). Likewise, the mean joint line convergence angle was 2.1° medial (95% confidence interval, 0.8° to 3.4° medial) for the patients for whom the standing radiograph was made before the fluoroscopic examination, compared with 1.5° medial (95% confidence interval, 0.6° to 2.4° medial) for those for whom the standing radiograph was made after the fluoroscopic examination (p = 0.46). The average pelvic height difference between the right and left sides on the standing anteroposterior radiograph was 13 mm (range, 0 to 53 mm).

The correlation coefficient (r) for the measurement of mechanical axis deviation with use of the two radiographic methods was 0.88, implying a strong correlation for the 102 limbs. When the analysis was repeated with use of only one of the two limbs that were randomly chosen for the twenty-two limbs that were evaluated with fluoroscopy (p = 0.41). The mean absolute difference between the two imaging techniques for the measurement of the joint line convergence angle was the same (2.8°) for the entire study population and for the subgroup of eighty limbs (p = 0.92).
patients in whom both limbs were evaluated with fluoroscopy, the correlation coefficient (r) was 0.87 and thus was very similar to the result obtained for the entire study population. The results of linear regression analysis demonstrating the relationship between the standing radiograph and fluoroscopy for the measurement of mechanical axis deviation are shown in Figure 3. Limbs with >2 cm of mechanical axis deviation on the standing radiograph were more likely to have >10 mm of discrepancy in the measurement of mechanical axis deviation with use of the two radiographic methods (p < 0.0001) (Table II). Similarly, limbs with a joint line convergence angle of >3° as measured on the standing radiograph were more likely to have >10 mm of discrepancy in the measurement of mechanical axis deviation with use of the two imaging techniques (p = 0.003). In eighteen of the twenty limbs that were noted to have a joint line convergence angle of >3° on the standing radiograph, the apex was medial (mean, 8°; range, 4° to 27°), indicating varus malalignment. In all twenty-six limbs that were noted to have a joint line convergence angle of >3° on fluoroscopic images, the apex was medial (mean, 7°; range, 4° to 18°). In addition, patients with the primary diagnosis of "limb deformity" were significantly more likely to have >10 mm of discrepancy in the measurement of mechanical axis deviation with use of the two imaging modalities when compared with those who had another diagnosis, such as limb-length discrepancy or fracture (p = 0.0001) (Table II).

The difference in the measurement of mechanical axis deviation between the standing radiograph and fluoroscopy was plotted against the mean mechanical axis deviation with use of the two techniques for each limb (see Appendix). The mean difference in mechanical axis deviation between the standing radiograph and fluoroscopy was 0.6 mm lateral (95% confidence interval, 36.6 mm lateral to 35.4 mm medial). There was a trend for the standing radiograph to demonstrate greater mechanical axis deviation in comparison with fluoroscopy as the severity of varus malalignment of the limb increased.

Multivariate regression analysis revealed a positive relationship between the patient’s body mass index and the magnitude of discrepancy in the measurement of mechanical axis deviation with use of the two radiographic techniques (p = 0.0014). Furthermore, limbs with the diagnosis of “deformity” were more likely to have >10 mm of discrepancy in the measurement of mechanical axis deviation between the two radiographic methods (p = 0.002). With the numbers studied, we found no significant relationship between the remaining variables (including age [p = 0.06], gender [p = 0.85], the side of the imaged extremity [right or left] [p = 0.49], the magnitude of pelvic height difference [p = 0.99], the direction of malalignment [p = 0.26], the timing of the fluoroscopic examination [before or after the standing radiograph was made] (p = 0.91), the magnitude of mechanical axis deviation [p = 0.88], and the magnitude of joint line convergence angle [p = 0.36]) and the difference in the measurement of mechanical axis deviation that was obtained with use of the two radiographic techniques (see Appendix).

**Discussion**

Recreating the normal alignment of the lower extremity is a key factor in achieving a satisfactory outcome following long-bone fractures and limb reconstruction. Thus, having a reliable means to evaluate lower limb alignment both intraoperatively and in the outpatient setting is vital for the management of such patients.

The distance between the center of the knee and the mechanical axis line is referred to as the mechanical axis deviation, with a proposed normal value of 10 mm medial (range, 3 to 17 mm medial) on a standing full-length radiograph. In the current study, we found an overall strong (r = 0.88), although not perfect, correlation between the use of a standing radiograph and the use of supine fluoroscopy for assessing mechanical axis deviation. A mean absolute difference of 13.4 mm (p < 0.0001) was noted between the mechanical axis deviation measured on the standing radiograph and the fluoroscopic images. Given that the average width of the distal part of the femur in our patients was 73 mm, the mean difference between the two imaging techniques corresponds to approximately 18% of the width of the knee joint. Although the clinical relevance of this magnitude of difference remains speculative, none of the patients in the current study required additional surgery related to the discrepancy in the measurement of limb alignment with use of the two techniques.

In addition to osseous deformities, an abnormal mechanical axis deviation also may be secondary to soft-tissue laxity around the knee. Normally, the femoral condyles and tibial plateau are essentially parallel, with a joint line convergence angle of 0° to 2° medial. In patients with collateral ligament laxity or substantial intra-articular bone loss, the two
articular surfaces may not remain parallel, with a consequent increase in the joint line convergence angle and mechanical axis deviation. This situation is often noted in patients with advanced stages of early-onset Blount disease\textsuperscript{20}, malunited intra-articular fractures of the knee\textsuperscript{1}, or severe arthritis with bone loss of the tibiofemoral articulation.\textsuperscript{1} In limbs with excessive ligamentous laxity of the knee, as indicated by a joint line convergence angle of $>3^\circ$, we found that the fluoroscopic examination was less reliable. It is possible that if we had axially loaded the extremity during the fluoroscopic examination, the mechanical axis deviation and joint line convergence angle measurements would have shown less discrepancy between the two imaging studies. We also noted a trend for the standing radiograph to reveal a greater magnitude of mechanical axis deviation in comparison with fluoroscopy as the severity of varus malalignment of the limb increased. This makes intuitive sense, as the axial forces across the knee joint are substantially larger during weight-bearing as opposed to the supine position.\textsuperscript{1}\textsuperscript{1}. In the neutrally aligned knee, the ground-reaction forces pass just medial to the joint center, creating an adduction moment that increases medial compartment forces relative to the lateral side. With increasing varus malalignment, the moment arm for the ground-reaction force vector is further increased.\textsuperscript{21} The knee joint is dependent on the integrity of the soft-tissue restraints, including the collateral ligaments, for medial and lateral stability. The lateral collateral ligament complex and the iliotibial band provide the primary soft-tissue restraints to lateral joint opening. Knee joints with varus malalignment and a high adduction moment can thus open up laterally, especially with weight-bearing, creating a larger magnitude of mechanical axis deviation than can be accounted for by the skeletal deformities alone.

On the basis of our multivariate regression analysis, the patient's body mass index and an underlying diagnosis of "deformity" were the only variables that reached significance. An obese patient with large thighs has difficulty adducting the hip adequately and may produce a varus moment on the knee on the standing radiograph. Moreover, during intraoperative supine fluoroscopy, there may be greater distortion of the path of the electrocautery cord because of the increased vertical distance between the hip and ankle joints in heavier patients. While we noted a greater difference in the measurement of the mechanical axis deviation between the standing radiograph and fluoroscopy as the magnitude of mechanical axis deviation and the joint line convergence angle increased (Table II and Appendix), such observations were not supported by the multivariate analysis. It is possible that individuals who had a larger magnitude of mechanical axis deviation and the joint line convergence angle were also overweight, as is often the case for patients with Blount disease.\textsuperscript{20} We also noted a tendency for the limbs with "deformity" to show a greater magnitude of discrepancy in the measurement of mechanical axis deviation with use of the two imaging techniques. As 50\% of the limbs with a diagnosis of "deformity" were in patients who had Blount disease, our findings further support this hypothesis. Although the effect of patient age on the discrepancy between the two imaging modalities in the measurement of mechanical axis deviation did not achieve significance ($p = 0.06$), there was a trend for greater variability in the estimation of mechanical axis deviation in younger patients. These findings may be related to the lack of complete ossification of the osseous landmarks in children, along with greater soft-tissue laxity and difficulty in properly positioning young children for the standing radiograph.

Our study had several limitations. First, as it was a retrospective study, only a small percentage (approximately 12\%) of the patients who underwent lower limb osteotomy, epiphysodesis, knee arthrography, or hardware removal had both imaging studies performed. Second, there is a potential for selection bias as the decision to use intraoperative fluoroscopy for assessing limb alignment was based entirely on the discretion of a single surgeon. Although we used a standardized technique for performing the evaluations with use of the supine fluoroscopy and standing radiographs, the indications for these imaging studies were not consistent. The intraoperative fluoroscopic measurements were compared with standing radiographs that had been made preoperatively for some patients and postoperatively for others. It is possible that had we employed a consistent protocol for making the standing radiograph at a certain time-period before and/or after the fluoroscopy, the correlation between the two methods would be higher. Third, true reliability of the fluoroscopic method with regard to placement of the electrocautery cord over the hip, knee, and ankle joints could not be measured in this retrospective study. Although we did attain satisfactory intraobserver reliability for the measurement of the mechanical axis deviation and the joint line convergence angle with use of the two imaging methods, the intraobserver and interobserver variability of the electrocautery cord technique itself was not assessed as the reliability of locating the center of the femoral head and distal part of the tibia with use of the fluoroscopic technique was not evaluated. Moreover, we did not utilize specific templates or detailed measurements for identifying these osseous landmarks intraoperatively. With the fluoroscopic method, the electrocautery cord tends to show kinks and if it comes in contact with the skin anywhere between the hip and the knee, its path may be changed even when under stretch, thus compromising the accuracy of assessing the mechanical axis deviation. Furthermore, the electrocautery cord is not usually held parallel to the operating room table because the anterior aspect of the hip is farther from the table than the anterior skin of the ankle is. If the cord is anchored at the hip and is held parallel to the table, it will not touch the knee and thus errors related to parallax may compromise accurate assessment of limb alignment. Another radiographic method that may circumvent some of these issues is to use a fixed alignment grid under the lower limb, with the hip and ankle centered over the grid lines.\textsuperscript{22} Finally, it is also possible that despite our radiographic protocol, some patients did not fully bear weight for the standing postoperative radiographs, with resulting underestimation of the mechanical axis deviation. Nonetheless, when we compared the mechanical axis deviation...
and joint line convergence angle of the patients for whom the standing radiographs had been made before fluoroscopy with those for whom the standing radiographs had been made after fluoroscopy, no significant difference was noted between the two groups.

In summary, we found a strong correlation between supine fluoroscopy and the standing anteroposterior radiograph of the entire lower extremity for the measurement of mechanical axis deviation. We conclude that surgeons performing mechanical realignment of the lower extremity to address frontal plane deformities in patients who are not obese can be fairly confident of the intraoperative estimation of the lower limb alignment with use of the fluoroscopic electrocautery cord technique. However, the results of fluoroscopy should be interpreted with caution in individuals who are obese or who have substantial residual mechanical axis deviation or pathologic laxity of the knee joint.

Appendix

A graph depicting the relationship between the mean mechanical axis deviation and differences in mechanical axis deviation as measured with the two techniques as well as tables showing the multivariate analysis of the effect of continuous and categorical variables on the discrepancy in the measurement of mechanical axis deviation with use of the two radiographic methods are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on “Supplementary Material”) and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM).

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References