Title: The Flexion Lateral Radiograph in the Evaluation of Total Knee Arthroplasty

Running Title: The Flexion Lateral Knee Radiograph

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**Word Count:** 2,609 (Introduction through Discussion)

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Abstract

This study is a retrospective comparative cohort radiographic analysis of 114 consecutive patients who underwent posterior cruciate retaining (PCR) TKA, medial and patellofemoral compartment bicruciate retaining arthroplasty (BCR), or bicruciate substituting (BCS) TKA. In an effort to obtain a quantitative measurement of both AP tibiofemoral position and active knee flexion we have routinely taken postoperative lateral radiographs in a position of maximal active flexion. AP tibiofemoral position and active knee flexion were measured and compared between groups. The mean radiographically projected rollback of the PCR (-1.23mm) and BCR (-3.30mm) were statistically less than the BCS (-11.95mm). Pre op ROM was 104, 109.1, and 106.8 degrees for the PCR, BCR, and BCS respectively. The mean active postoperative flexion for PCR (100.3 degrees) was statistically lower than the BCR (115.6 degrees) and BCS (118.1 degrees). Posterior rollback measurements observed in this study with different TKA designs were similar to the rollback reported in previous weight bearing in vivo fluoroscopic studies. Our findings indicate that tibiofemoral AP translation and knee flexion can be assessed on an active flexion lateral knee flexion radiograph and provides additional information that is not available from a routine lateral radiograph.

Level of Evidence: Diagnostic Level III.
**Introduction:**

The post operative radiographic evaluation of a total knee arthroplasty (TKA) generally includes weight bearing anteroposterior, non weight bearing lateral, and axial patellar views. These images are used to assess the mechanical integrity of the bone implant interfaces, component alignment, bony abnormalities, and patellar problems. However, the position of knee flexion for the lateral radiograph may be quite variable. Usually the lateral radiograph is taken at approximately 30 degrees, which is a comfortable position of flexion for most patients [6].

Assessment of the anteroposterior (AP) position of the distal femur relative to the proximal tibia during weight bearing activity or kinematic analysis requires detailed measurements with in vivo fluoroscopy [4,7-11]. This type of analysis is used as a research tool and not performed in routine clinical practice. However, knee kinematics can affect joint function and therefore an assessment of kinematic behavior after TKA may be useful in standard clinical practice.

During flexion beyond 50 to 60 degrees, the tibial tubercle is anterior to the patella, resulting in a posteriorly directed force on the tibia transmitted from the quadriceps through the patellar tendon [14,25,28]. Femoral rollback during flexion increases the extensor mechanism moment arm, which affects the efficiency of the quadriceps. The anterior tibiofemoral shear force is resisted by the cruciate ligaments and the tibiofemoral contact pressures. In a posterior stabilized TKA the anterior tibiofemoral shear force is
also resisted by the cam post mechanism. Therefore a lateral radiograph taken with the knee in maximal flexion may provide an assessment of the kinematic restraint to anterior femoral translation on the tibia. Our study questioned whether a lateral radiograph with the knee in a position of maximum active flexion could provide more clinical information than a routine lateral radiograph without any additional radiation exposure or expense. In an effort to obtain a quantitative measurement of both AP tibiofemoral position and active knee flexion we have routinely taken our postoperative lateral TKA radiographs in a position of maximal active flexion. The purpose of this study was to determine if an active flexion lateral radiograph would provide a simple inexpensive quantitative measurement of AP tibiofemoral position and active knee flexion, which correlated with similar information from more complex in vivo fluoroscopic kinematic studies.

Methods:

This study is a retrospective comparative cohort radiographic analysis of 114 consecutive TKA patients. Pre-operative and postoperative clinical, demographic, radiographic, and functional outcome data from all of our TKA patients was collected prospectively and entered into a database which served as a source of information used in this study. Patients were evaluated clinically and radiographically at three months, six months, and yearly thereafter with standing anteroposterior, flexion lateral, and 30-degree patellar radiographs. The patient is positioned supine for the flexion lateral radiograph and actively flexes the knee as much as possible (Figure 1).
Measurements of AP tibiofemoral position and maximum active knee flexion were compared in 114 consecutive TKA patients separated into three groups. This totaled 127 TKA implants, of which 13 patients had received bilateral TKAs. Group 1 consisted of 48 patients with 55 posterior cruciate ligament retaining (PCR) TKAs (Genesis II, Smith and Nephew, Memphis, TN), group 2 consisted of 42 patients with 42 bicruciate ligament retaining (BCR) medial and patellar bicompartamental arthroplasty (Deuce, Smith and Nephew, Memphis, TN), and group 3 consisted of 24 patients with 30 bicruciate ligament substituting (BCS) TKAs (Journey, Smith and Nephew, Memphis, TN).

One of the authors (MR) had routinely performed PCR TKAs for patients with less than 20 degrees of combined axial (varus-valgus) and flexion deformity and PS TKA’s for patients with greater than 20 degrees of deformity until March 2005 when the BCS TKA became available and then routinely used a BCS TKA for all primary TKAs. Radiographs for patients in groups 1 and 3 were obtained from this author’s practice.

Another author (LR) routinely used a BCR bicompartamental arthroplasty during the study period for patients with medial and patellofemoral arthritis. Radiographs for patients in group 2 were obtained from this author’s practice.

Radiographic measurements were obtained from the most recent post operative flexion lateral radiograph to determine tibiofemoral AP position and the amount of active knee flexion. Both surgeons used a standard protocol of 6 week, 3 month, 6 month and annual clinical and radiographic follow up. In order to allow comparison of the measurements to previous in vivo studies, the method by Dennis et al, with a variation,
was utilized [7-10] and the analysis was performed by a single observer. The femorotibial contact point was determined and the tibiofemoral AP position calculated in relation to the mid sagittal point of the tibial baseplate (Figure 2). However, the tibiofemoral contact point after TKA observed on a lateral radiograph does not distinguish between contact in the medial or lateral tibiofemoral compartment. The PCR and BCS replace both compartments while the BCR replaces the medial but not the lateral tibiofemoral compartment (Figure 3). Therefore the contact point of the BCR seen on a lateral radiograph was considered to represent contact in the medial compartment and the contact point of the PCR and BCS was considered to represent the more posterior tibiofemoral compartment (Figure 4).

Active knee flexion was measured radiographically using a digital goniometer (Figure 3). AP position and knee flexion were compared between groups as well as post operative Knee Society Score (KSS) values using ANOVA. Pre operative demographic data (age, gender, BMI, and passive knee range of motion) were compared between the groups as well as the most recent post operative KSS and passive range of motion values using ANOVA (Table 1). These values were obtained at the same time that the most recent post operative radiograph was obtained for measurement, which is listed as the mean follow up time for each groups in Table 1. All comparisons were performed using a single factor ANOVA, where the level of significance was set at an alpha value of 0.05.
Results:

The mean rollback of PCR was -1.23mm, BCR was -3.30mm and BCS was -11.95mm. Radiographically projected rollback of both the BCS and BCR were greater than the PCR (P < 0.001) and radiographically projected rollback of the BCS was greater than the BCR (P < 0.001). The mean active flexion for PCR, BCR, and BCS was 100.3 degrees, 115.6 degrees, and 118.1 degrees, respectively. Mean active flexion for both the BCS and BCR were greater than the PCR (P < 0.005). There was not a statistically significant difference in mean active flexion between the BCR and BCS (p=0.42). (Table 1)

A comparison of pre operative demographic data between the three groups demonstrated no differences in age, gender, or passive range of motion. Pre operative BMI was greater for the BCS group compared to both the PCR and BCR groups (p<0.001). There was no difference between the PCR and BCR with regard to BMI.

Passive range of motion after TKA was significantly greater than pre operative range of motion for all three groups (p< 0.05) (Table 1). Postoperative passive range of motion of the BCS was greater than the PCR (p<0.003) and BCR (p<0.03). Postoperative passive range of motion of the BCR was greater than the PCR (p<0.001). There was a significantly higher (p<0.05) post operative pain KSS for both the BCR compared to PCR and BCS compared to PCR; however, there was no statistical difference in pain KSS between the BCR and BCS. There was no statistical difference in post-operative function based upon KSS values between any of the three groups.
Discussion:

Kinematics after a knee replacement are affected by the implant design. The cam and post mechanism of posterior stabilized knees results in less anterior tibial subluxation during knee flexion than posterior cruciate retaining knees [4,8,16,33]. However, fluoroscopic in vivo motion imaging during active knee flexion has been required to differentiate the kinematic patterns of different knee designs [2,4,7-10,15,19,32]. Our findings indicate that AP translation between the distal femur and proximal tibia during knee flexion can also be assessed on an active knee flexion lateral radiograph and provide additional information that is not available from a routine lateral radiograph.

However, the tibiofemoral contact point of a TKA measured on a single lateral radiograph does not differentiate between the contact between the medial or lateral condyle and tibial component. In order to determine if the flexion lateral knee radiograph provided a viable method to evaluate post-operative femoral rollback, it was necessary to correlate the radiograph measurements qualitatively and quantitatively with in vivo kinematic data. Since fluoroscopic kinematic studies report posterior rollback of both the medial and lateral condyles separately, we compared the posterior position of the femorotibial contact point of the PCR and BCS TKA measured on an active flexion lateral radiograph with the contact point of the most posterior condyle reported in fluoroscopic kinematic studies which commonly is the lateral condyle. However for the BCR TKA, the medial compartment is replaced and not the lateral; thus, medial
tibiofemoral contact points were measured and compared to previous in vivo kinematic data.

Dennis et al. showed that for PCR TKA designs, when measured at 90 degrees of flexion in a standing deep knee bend, the medial femoral condyle contact point was measured at a mean of -2.3mm with a range -6.8mm to 3.9mm (+/- 3.7mm) [7]. The mean lateral femoral condyle contact point was measured at -7.4mm (range -15.3 to -1.2mm +/- 1.3 mm) [7-11]. Using a similar measurement method for rollback and by measuring the most posterior point of contact, the data from our study showed a mean of -1.23 mm for PCR TKA designs (range -10 to 9mm +/- 3.8 mm). Furthermore, a multicenter fluoroscopic kinematic study by Dennis et al, showed in 136 patients with a PCR total knee arthroplasty, the mean lateral condylar motion was -1.6mm (range -6.4 to 4.7mm, +/- 3.4mm) and the mean medial condylar motion was +1mm (-4.3 to 6.3mm, +/- 3.5mm) [8,9]. In our study, the mean values and ranges are similar to the above reported multicenter mean lateral condyle motion and would substantiate this diagnostic modality as a comparable qualitative assessment of tibiofemoral rollback in TKA patients.

Radiographically projected rollback for the BCS group was greater than for the BCR group. However, rollback after BCS TKA likely represents lateral tibiofemoral contact, which would be expected to be greater and more posterior than medial tibiofemoral rollback seen after BCR knee arthroplasty.

Our BCR results of -3.30mm mean posterior medial condyle rollback were noted to be slightly less than values reported by Stiehl et al, in a kinematic study which
evaluated 16 of 22 subjects who received a BCR TKA and had mean femoral condyle rollback values of -4.3mm and -7.7mm, medial and lateral compartments respectively [29]. In comparison to the medial unilateral knee arthroplasty (UKA), which has classically required retaining the cruciate ligaments, Argenson et al showed a mean rollback of -0.8mm at 90 degrees flexion for 17 patients; and Akizuki et al reported a mean rollback of -5.3mm at maximum flexion in 30 medial (high flexion) UKA designs implanted in 18 patients [1,3]. While our reported mean fell within this range referenced in the above UKA literature, our values did show a similarity to previous natural knee kinematics for the medial tibiofemoral contact point, which was reported by Komistek et al to be -3.80mm (-7.4 to 1.4 +/- 3.5mm) [21].

Catani et al. evaluated the same BCS TKA implant used in this study with in vivo fluoroscopy and found the mean total lateral femoral condyle rollback/translation to be -15.5mm, which was similar to previously published biomechanical natural tibiofemoral contact point data reported by Draganich et al. of -13.5mm [5,12]. Furthermore, Komistek et al. reported natural knee lateral femoral rollback at 90 degrees deep knee bend to be -13.7mm (range -22 to -.05mm +/- 8.4mm) [21]. The BCS data obtained from our study showed mean values similar to this and would suggest that the BCS design has improved rollback compared to conventional PCR designs and has rollback similar to previously reported data for bicruciate retaining TKA and normal natural knee kinematics [12,15,21,23,24,27].
Kinematics of the normal knee are well defined [8,12,17,18,20,21,23,24]. As the knee flexes, the lateral femoral condyle moves posteriorly more than the medial femoral condyle resulting in femoral rollback and external rotation of the tibia on the femur (screw home mechanism). However, after a total knee arthroplasty, the knee kinematics can be markedly altered. In extension, the tibia is typically subluxated anteriorly as a result of ACL insufficiency and during knee flexion the femur moves anteriorly with paradoxical motion [7,8,10,30]. Flexion instability may develop, particularly in posterior cruciate retaining knees resulting in further anterior subluxation of the femur during knee flexion [22,30,31]. A lateral radiograph of the knee in flexion can be helpful to illustrate anterior femoral subluxation and diagnose flexion instability [26].

Knee range of motion is an important outcome variable used to assess the results of TKA. Passive range of motion is usually reported and can be measured by a single or multiple observers using a hand held goniometer or as a visual estimation of knee motion. However, radiographs may permit a more objective measurement of knee motion since the skin and soft tissues do not affect the measurement. Edwards et al. evaluated 27 knees in 16 patients by blinding three examiners who then made visual and surface goniometer measurements on flexed knees [13]. The same flexed knees were then evaluated with a radiograph and the flexion angle measured. While the non radiographic measurements had high interobserver and intraobserver correlation coefficients, of 0.79 and 0.92 respectively, they found that visual measurements and skin surface goniometer measurements were off by more than 5 degrees when compared to the radiographic measurements 45% and 22% of the time, respectively [13]. While BMI did not play a
role in significantly limiting the visual and flexion goniometer measurements, it did aid in identifying that true flexion might be better measured by radiographic evaluation. Dennis et al found that weight-bearing passive deep knee bend activity was statistically greater in PCS than PCR TKAs [7,11]. The active flexion radiograph illustrated in this study permits quantification of knee motion. We found that active knee flexion is less than passive knee flexion in all three designs, but the groups with greater passive knee flexion also had greater active knee flexion. Groups with greater active knee flexion also tended to have more normal posterior femoral rollback. While many factors affect the functional result achieved after TKA, active knee range of motion may be an important outcome variable, which can be used along with other outcome measurements to assess the functional result after TKA.

Despite the important findings in this study, there are some limitations which should be considered when interpreting the results. This is a retrospective study with slightly different indications for surgery between patients in different groups. The patients were not individually matched and there was a higher BMI in the BCS group compared to the other two groups. Although the results correlated well with historical controls, the AP position seen on the flexion lateral radiograph was not validated with a fluoroscopic kinematic analysis.

A routine lateral radiograph after TKA is generally used to provide information about bony anatomy and implant position. The maximum active flexion lateral knee radiograph provides a means to measure the AP tibiofemoral position and active knee
flexion as well as the visualization of bone and implant detail. The additional information provided on the active lateral radiograph can help to assess knee kinematics and active range of motion without any additional radiation exposure or cost. We believe that the flexion lateral radiograph is a reliable, valuable and cost effective diagnostic tool in the routine postoperative assessment of TKA patients.

References:


27. Ries MD. “Effect of ACL sacrifice, retention, or substitution on kinematics after TKA”. Orthopaedics. 2007; 30:74-76.


Figure Legends:

Figure 1A. A lateral view diagram illustrates the flexion lateral radiograph. The patient is positioned supine on the x-ray table, and actively flexes the knee as much as possible. The patient or an assistant does not further passively flex the knee. A cross table lateral radiograph of the knee is taken to include the distal femur and proximal tibia.

1B. An orthogonal view illustrates the direction of the x-ray beam.

Figure 2. A flexion lateral radiograph of a PCR TKA. The anteroposterior tibiofemoral position is determined by measuring the length of the tibial baseplate and the most posterior contact point.
between the femoral condyle and the tibial baseplate. The baseplate length (AB) was measured
on the lateral radiograph and a mid sagittal point (C) of the baseplate was obtained by dividing
the baseplate length in half. Next, a line parallel to the baseplate (DE) was drawn which
contacted the articulating surface of the femoral prosthetic component. The most posterior point
of the femoral condyle contact (F) was marked once that parallel line touched the femur and an
orthogonal line (GH) was drawn vertically to represent this posterior contact point on the tibial
baseplate (I). The distance measured from the most posterior edge of the tibial baseplate to that
contact point (BI) was determined and was subtracted from the distance from the mid sagittal mid
point value to the posterior baseplate (BC) in order to determine the amount of rollback. Contact
points posterior to the mid sagittal line were considered as negative values, which correlated to
normal femorotibial rollback. Contact points that were anterior to the mid sagittal line were given
positive values, which correlated to paradoxical rollback. In this example, the tibial baseplate
length (AB) is 52mm, the mid sagittal point (C) is 26mm anterior to the posterior border of the
tibial baseplate (BC), the femorotibial contact point (I) is 22mm anterior to the posterior border of
the tibial baseplate (BI), the rollback is -4mm, and active knee flexion angle is 98degrees.

Figure 3. A flexion lateral radiograph of a BCR TKA illustrating the flexion angle of the knee
and femorotibial contact point. The amount of active knee flexion is determined by the angle
formed by a longitudinal line drawn parallel to the posterior border of the distal femoral diaphysis
and a line drawn parallel to the posterior border of the proximal tibial diaphysis. The tibial
baseplate length is 54mm, the mid sagittal point is 27mm anterior to the posterior border of the
tibial baseplate, the medial femorotibial contact point is 21mm anterior to the posterior border of
the tibial baseplate, the rollback is -6mm, and active knee flexion angle is 130degrees.

Figure 4. A flexion lateral radiograph of a BCS TKA illustrating the femorotibial contact point.
The tibial baseplate length is 56mm, the mid sagittal point is 28mm anterior to the posterior
border of the tibial baseplate, the femorotibial contact point is 18mm anterior to the posterior border of the tibial baseplate, the rollback is -10mm, and active knee flexion angle is 128 degrees.
Table 1: Demographic Data and Results

<table>
<thead>
<tr>
<th>Overall Results</th>
<th>PCR (mean)</th>
<th>BCR (mean)</th>
<th>BCS (mean)</th>
<th>Statistical Significance</th>
</tr>
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<tbody>
<tr>
<td>Age</td>
<td>70.3</td>
<td>67.3</td>
<td>65.3</td>
<td>P=0.051</td>
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<tr>
<td>Gender (F:M)</td>
<td>37/18</td>
<td>21/21</td>
<td>15/15</td>
<td>P=0.13</td>
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<td>BMI</td>
<td>30.1</td>
<td>29.5</td>
<td>34.1</td>
<td>P=0.001</td>
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<tr>
<td>F/U (Months)</td>
<td>61.2</td>
<td>10.5</td>
<td>27.6</td>
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<tr>
<td>PreOp PROM (Degrees)</td>
<td>104</td>
<td>109.1</td>
<td>106.8</td>
<td>P=0.20</td>
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<tr>
<td>PostOp PROM (Degrees)</td>
<td>115.2</td>
<td>121.3</td>
<td>125.3</td>
<td>P&lt;0.001</td>
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<tr>
<td>Rollback (mm)</td>
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<td>-3.30</td>
<td>-11.96</td>
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<tr>
<td>PostOp AROM (Degrees)</td>
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<td>115.6</td>
<td>118.1</td>
<td>P&lt;0.001</td>
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<td>PostOp KSS (Pain)</td>
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<td>PostOp KSS (Function)</td>
<td>70.6</td>
<td>75.5</td>
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<td>PostOp KSS (Total)</td>
<td>151.5</td>
<td>164.6</td>
<td>159.1</td>
<td>P=0.16</td>
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</table>

PCR=Posterior Cruciate Retaining; BCR=Bicruciate Retaining; BCS=Bicruciate Substituting; F=Female; M=Male; BMI=Body Mass Index; F/U=Follow Up; PreOp=Preoperatively; PROM=Passive Range of Motion; PostOp=Postoperatively; mm=millimeters; KSS=Knee Society Scores
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