Frontal Plane Kinematics Including Condylar Lift-Off and Medial to Lateral Translation Were Investigated in 10 Patients Who Had Total Knee Arthroplasty With a Mobile-Bearing Rotating Platform or a Similar Implant That Had Been Modified With a Posterior Stabilizer. The Rotating Platform Had Condylar Lift-Off (Average, 2 mm) and Medial Tibial Translation (Average, 4.3 mm) in All Implants Tested. The Posterior-Stabilized Prosthesis Had Significantly Less Condylar Lift-Off (Average, 1.2 mm) and Medial Translation (Average, 1.7 mm). The Difference Is Attributed to Constraint of the Posterior Stabilizer Mechanism in the Frontal Plane. The Important Kinematic Functions of Frontal Plane Condylar Lift-Off and Medial to Lateral Translation Must Be Accounted for by Contemporary Total Knee Prosthetic Designs Because Abnormalities May Lead to Abnormal Wear and Loss of Prosthetic Fixation.

Prosthetic performance after total knee arthroplasty is a complex multivariate function that depends on implant design, surgical technique, anatomic factors, and patient rehabilitation. Accurate kinematic determination of the knee tibiofemoral articulation have been investigated with several methodologies including roentgen stereophotogrammetric analysis, high-speed photogrammetry analysis with intracortical pins, and dynamic video fluoroscopy. Based on those studies, consistent reproducible information has led to a greater understanding of exactly how total knee implants will articulate in vivo.

1,3–6,9–15,17–22 Frontal plane condylar lift-off has been identified in normal knees and with most total condylar knee prosthetics regardless of cruciate ligament preservation, sacrifice, or substitution.6,9–15,18 Although inferential, it has been suggested that this kinematic function may be related to certain implant failure mechanisms such as fixation breakdown or polyethylene articular surface wear.2,21,22 Frontal plane medial to lateral translation has been shown to occur in normal knees, anterior cruciate-deficient knees, and knees that had total knee arthroplasty using previously described techniques.8–15 It is known that the proximal tibia translates medi ally with increasing flexion in normal and anterior cruciate-deficient knees.9–13 The results with investigation of a total knee prosthesis showed variable medial and lateral translation although in a nonweightbearing mode.14,15

The current authors used in vivo dynamic video fluoroscopy to evaluate kinematics of total knee arthroplasty in the frontal plane. An
implant was chosen that allowed sacrifice or substitution of the posterior cruciate ligament but an identical surgical technique and prosthetic geometry were used. The null hypothesis was that frontal plane kinematics are not affected by the presence of a central posterior stabilizer in a mobile-bearing knee prosthesis.

MATERIALS AND METHODS

Ten patients were selected who had total knee arthroplasty using the LCS mobile-bearing rotating platform prosthesis (Depuy and Johnson and Johnson, Warsaw, IN). Five patients received the standard cruciate-sacrificing rotating platform device and five patients had the newer posterior-stabilized version. All patients had a minimum followup of 6 months and were judged to have clinically successful results with an excellent result (Knee Society score of $>90, 90$) with no evidence of ligamentous laxity or pain. From prior experience, the 6-month interval allowed adequate determination of baseline kinematic function. The surgical technique for the LCS rotating platform prosthesis requires that the cruciate ligaments were excised followed by the initial bone cut of the proximal tibial surface done with an extramedullary alignment jig. The posterior condyles were resected using a flexion spacing technique whereas the distal femoral cut was made using an intramedullary alignment guide. Careful balancing of the ligaments with perfect match of the flexion and extension gaps was done before final insertion of implants. All patients were operated on by one surgeon (BH) and the same postoperative rehabilitation protocol was used for all patients.

Frontal plane in vivo video fluoroscopy was done of each patient doing a deep knee bend. This was done by having the patient stand in a precise position with the knee in full extension followed by flexing to the maximal amount allowed (at least $90^\circ$). The radiographic device was a high frequency pulsed fluoroscopy unit (PNF Dynamics, Tampa Bay, FL). Two-dimensional fluoroscopic images were stored on videotape for subsequent redigitization using a frame grabber. The contact position between the femur and tibia was determined using an automated three-dimensional model fitting technique. This method requires that the frontal plane video images are captured on the workstation computer. The three-dimensional computer-aided design solid models of the femoral and tibial components then are overlaid onto the two-dimensional fluoroscopic perspective images. The automated system allows the three-dimensional model to seek the best fit (Fig 1). Medial to lateral translational measurements then were made from the center of

![Fig 1A–D](image_url)

(A) The frontal plane video fluoroscopic image of the posterior-stabilized LCS rotating platform total knee replacement is shown. (B) The three-dimensional computer-aided design overlay of the image in Figure 1A is shown. (C) The frontal plane image of the standard rotating platform LCS total knee prosthesis is shown. (D) The three-dimensional computer-aided design overlay of the image shown in Figure 1C is shown.
the tibial baseplate to the femorotibial contact point of the medial condyle (Fig 2). Condylar lift-off was measured by calculating the difference of medial and lateral condyle contact distance in the frontal plane. The translational error for this process was determined to be less than 0.5 mm.²

**RESULTS**

Patients with the LCS rotating platform tibial insert experienced an average medial translation of the tibial plateau of 4.3 mm (range, 1.5–7.4 mm). The LCS posterior-stabilized tibial insert had significantly (p < .05) less medial tibial translation with an average of 1.7 mm (range, 1.2–2.6 mm). Condylar lift-off of the LCS rotating platform averaged 2 mm (range, 1.1–3 mm) whereas the LCS posterior-stabilized had an average of 1.2 mm (range, 0.6–2.8 mm) which was significantly less (p < .05). There was no significant correlation between the amount of medial tibial translation and condylar liftoff. No patient experienced lateral tibial translation (Fig 3) (Tables 1, 2).

**TABLE 1. Medial to Lateral Translation and Condylar Lift-Off for LCS Posterior-Stabilized Total Knee Prosthesis**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Medial to Lateral Translation (mm)</th>
<th>Condylar Lift-Off (mm)</th>
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<tbody>
<tr>
<td>1</td>
<td>1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>1.8</td>
<td>0.6</td>
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<tr>
<td>3</td>
<td>1.3</td>
<td>1.3</td>
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<tr>
<td>4</td>
<td>1.2</td>
<td>2.8</td>
</tr>
<tr>
<td>5</td>
<td>2.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Average</td>
<td>1.7 (p &lt; .05)</td>
<td>1.2 (p &lt; .05)</td>
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Fig 2. The method of determining frontal plane condylar translation measuring from the center of the medial femoral condyle to the center of the tibial tray is shown.

Fig 3A–B. Examples of (A) neutral position and (B) medial tibial translation and lateral condylar liftoff in a rotating platform LCS total knee prosthesis are shown.
In vivo photogrammetric gait analyses using intracortical skeletal pins have shown significant medial tibial translation in normal knees from heel strike to maximal flexion during the gait swing phase. LaFortune et al\textsuperscript{13} found an average of 5.6 mm (+/−2.8 mm) medial translation during the gait cycle and Ishii et al\textsuperscript{9} found an average of 1.1 mm (+/−2.6 mm). Those authors also had condylar lift-off that was defined as adduction moments on the order of 3.4° (+/−1.2°) to 5° (+/−1.7°) and abduction of 6.4° (+/−2.8°). From the current authors’ prior studies\textsuperscript{1} condylar lift-off approximates 1 mm.

Karrholm et al\textsuperscript{12} and Jonsson et al\textsuperscript{10,11} investigated in vivo normal and anterior cruciate deficient knees using roentgenographic stereophotogrammetric analysis without and with active weightbearing. Similarly, they observed medial tibial translation that was exaggerated in anterior cruciate-deficient knees with increasing flexion. Nilsson et al\textsuperscript{14} investigated several total knee prostheses and reported medial tibial translation with non-weightbearing flexion as much as 50°. The Miller-Galante (Zimmer, Warsaw, IN) and LCS meniscal-bearing posterior cruciate-retaining implants translated medially as much as 2 mm, which was significantly less than the normal knee (5 mm).\textsuperscript{14} However, the Tricon-M prosthesis had lateral tibial translation of as much as 2 mm from 20° to 50° flexion. This implant is a relatively constrained posterior-cruciate-retaining device and tests were not done with the patient weightbearing.\textsuperscript{15}

The current study showed a substantial amount of medial tibial translation of as much as 7.4 mm with a weightbearing deep knee bend. The LCS rotating platform device was designed with a coronal plane femorotibial articulation to allow for this motion while maintaining prosthetic congruity (Fig 4). The newer LCS posterior-stabilized tibial insert virtually blocks this motion because of the width of the post and fit within the intercondylar box (Fig 5). A maximum of 2.6 mm medial

### TABLE 2. Medial to Lateral Translation and Condylar Lift-Off for LCS Rotating Platform Total Knee Arthroplasty

<table>
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<th>Medial to Lateral Translation (mm)</th>
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</tr>
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<tbody>
<tr>
<td>1</td>
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<td>1.3</td>
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<tr>
<td>2</td>
<td>7.4</td>
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<td>Average</td>
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**DISCUSSION**

In vivo photogrammetric gait analyses using intracortical skeletal pins have shown significant medial tibial translation in normal knees from heel strike to maximal flexion during the gait swing phase. LaFortune et al\textsuperscript{13} found an average of 5.6 mm (+/−2.8 mm) medial translation during the gait cycle and Ishii et al\textsuperscript{9} found an average of 1.1 mm (+/−2.6 mm). Those authors also had condylar lift-off that was defined as adduction moments on the order of 3.4° (+/−1.2°) to 5° (+/−1.7°) and abduction of 6.4° (+/−2.8°). From the current authors’ prior studies on condylar lift-off, 1° approximates 1 mm.

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translation was identified in one patient. Because lateral condylar lift-off was identified in all of the current patients, there is concern that the combination of lift-off and blocked medial translation could lead to the problems of medial peripheral edge wear and overloading of the medial condylar fixation interfaces.

Blunn et al.\(^2\) investigated the wear patterns from numerous tibial polyethylene insert retrievals finding a substantially greater tendency for wear to occur on the medial condylar surfaces. Implants that have a flat-on-flat condylar geometry such as the PCA prosthesis (Howmedica, Rutherford, NJ), when combined with ligamentous laxity could lead to medial edge loading with peripheral pattern wear and fracture of the medial tibial plateau. Finally, implants that have intercondylar constraint and impingement such as the Kinematic prosthesis (Howmedica) could have significant polyethylene wear of the abutting intercondylar interfaces.\(^2\) Polyethylene wear relates to the occurrence of particle-induced osteolysis. Any kinematic mechanism that magnifies implant surface wear ultimately will cause osteolysis.

The importance of the current study is that a mechanism of kinematic function has been identified to occur in total knee arthroplasty, which may explain certain prosthetic failures and wear retrieval data. Faris et al.\(^8\) identified a major failure group with the AGC (Biomet, Warsaw, IN) flat-on-flat condylar posterior cruciate-retaining total knee arthroplasty when the highly successful tibial baseplate was substituted with an all-polyethylene device. Medial condyle lift-off possibly could lead to exaggerated medial edge loading and early failure. From the literature review, the occurrence of medial peripheral pattern wear is uncommon, identified with certain flat-on-flat condylar devices.\(^2\) Many prostheses were developed with a degree of coronal plane conformity such that medial tibial translation is allowed and wear would occur in a more generalized central portion of the medial condyle. Puloski et al.\(^16\) identified post wear on the medial surface of varus and valgus constrained posterior-stabilized prostheses indicating that substantial wear of polyethylene could occur that may exceed wear identified on the posterior post articulation in certain cases. Clearly medial tibial translation could be implicated as the mechanism for this observation.

This limited study has shown an important kinematic function in total knee arthroplasty. Total knee prostheses had a significant alteration of function if constraint such as a closely fitting posterior stabilizer was built into the prosthesis. Additional prosthetic designs must take into account the potential ill effects that may accrue from frontal plane motions such as medial tibial translation or condylar lift-off.

References