In Vivo Kinematic Analysis of a Mobile Bearing Total Knee Prosthesis

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Ten normal subjects and 10 patients with a posterior cruciate retaining mobile bearing total knee replacement performed successive deep knee bends under fluoroscopy to determine tibiofemoral contact positions. At full extension the average initial contact position for the normal and mobile total knee replacement was 6.2 mm (range, 4.8 to 12 mm) anterior, and -4.4 mm (range, 3.9 to 11 mm) posterior to the sagittal tibial midplane, respectively. At 60° flexion, the normal knee rolled back to -5.8 mm (range, -2.5 to -13.2 mm), whereas the mobile bearing total knee replacement rolled back to -9.2 mm (range, -4 to -17 mm). From 60° to 90°, normal knees rolled back to -7.8 mm (range, -5.8 to -13.8 mm), but the mobile bearing total knee replacement slid anteriorly to -5 mm (range, 2 to -12 mm). All mobile bearing total knee replacements had some form of roll back, but some slid anterior more than others. Five of 10 mobile bearing total knee replacements had some movement of the bearings while the others remained fixed. Patellar kinematics was similar to normal but reflected tibiofemoral abnormalities.

In total knee arthroplasty, knowledge of kinematic function is important in the understanding of the weightbearing forces and shear stresses applied to bearing surfaces. It is likely that abnormal kinematics are detrimental to the performance of a total knee replacement. From a mechanical point of view, low area line contact, typical of many posterior cruciate retaining designs, may cause higher localized stresses in the bearing surfaces leading to higher rates of wear.10,13,14,20,21,27 These stresses are a function of the load applied, the area of contact, and the velocity of shear applied to the polyethylene surface.5 Additional problems include abnormal stresses applied to fixation interfaces if anteroposterior (AP) translation is exaggerated or eccentrically located.16

Recent designs have sought to make contact surfaces more congruent with the aim of improving the area of contact. This increased congruency may lead to prosthetic constraint, which may be detrimental to implant bone fixation. Mobile bearing prostheses were created to optimize wear through highly congruent matched surfaces, replicating the meniscal function, while removing constraint in rotation by allowing the components to slide with each other.7–9,17,18,23

Posterior cruciate retention in total knee arthroplasty has been advocated as a means of preserving normal joint function, preserving the normal joint line, and allowing for minimal bone resection.1,15 The kinematic studies of the authors and their coworkers consistently have revealed unpredictable and abnormal kinematic function with this tech-

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Tibiofemoral contact is more posterior than normal in extension and often reveals a net anterior translation with knee flexion. This phenomenon is not implant design specific and was recognized with virtually all fixed bearing posterior cruciate retaining designs tested. The most important implication of this finding is that abnormal translation may lead to exaggerated surface wear and aggravate polyethylene delamination. Also, increased translation may lead to a to and for rocking phenomenon on the tibial prosthesis that jeopardizes long term fixation. The authors showed a significant decrease in weightbearing range of motion (ROM) in normal knees and knees that underwent total knee arthroplasty with major differences between posterior cruciate retaining and substituting designs with the latter having significantly greater weightbearing motion.11,26

Video fluoroscopy and computer photogrammetry have been used to characterize in vivo joint kinematics.3,4,11,31 In the authors' initial experience, computer vector analysis was used to determine tibiofemoral contact points through weightbearing ROM. More recently, the authors' have used three-dimensional computer assisted design matching of the particular implants resulting in more accurate spatial resolution. This study analyzes the kinematics of a meniscal bearing total knee replacement that retains the posterior cruciate ligament under in vivo weightbearing conditions using fluoroscopy and current image matching techniques.

MATERIALS AND METHODS

Ten normal subjects and 10 patients with a posterior cruciate retaining meniscal bearing total knee replacement (Low Contact Stress [LCS] design, Depuy, Inc, Warsaw, IN) underwent video knee fluoroscopy at Lehigh Valley Hospital using a Siemens model Siremobil 2000 Digital Mobile Xray Image Intensifier (Siemens, New York, NY). The patients selected with total knee replacements had an excellent clinical result (average, -96 New Jersey Knee Score) and had an average followup of 54 months.6 All surgeries were performed by a single surgeon (PAK). The knees were examined in the sagittal plane by making a true lateral fluoroscopic image while the patient performed three successive deep knee bends or squats to maximum flexion tolerated by each patient.

The videos were analyzed using an inverse perspective technique that uses image matching. Silhouette libraries containing three-dimensional computer assisted design drawings (1271) of femoral and tibial components were created by orienting the components at 1° increments. At each increment of flexion, two-dimensional fluoroscopic images were replaced by best fit three-dimensional computer assisted design drawings found in the femoral and tibial component libraries (Fig 1). Tibiofemoral contact was determined with positive connoting anterior to the midplane of the proximal tibial plateau (F) and negative, posterior. Patellofemoral contact (CD) was measured from the most anterior point of the tibial tray. The patellar ligament was defined by a line drawn from the tibial tuberosity to the most inferior point on the patella (BE). The angle between the patellar ligament and the longitudinal axis of the tibia was defined as the patellar ligament rotation angle (β). The angle between the patellar ligament and the longitudinal axis of the patella (AB) was the patellar rotation angle (θ). Each subject's ROM was recorded (Fig 2).

RESULTS

At full extension, all normal knees exhibited a positive tibiofemoral contact position with an average of 6.2 mm (range, 4.8 to -12 mm). Meniscal bearing total knee replacements started significantly more posterior in extension at -4.4 mm (range, 3.9 to -11 mm). For normal knees, most rollback or posterior translation occurred from 0° to 30°, whereas less posterior translation occurred beyond 30°. The meniscal bearing total knee replacement rollback or posterior translation occurred during the initial 30° flexion with diminished rollback from 30° to 60°. At 60° flexion, the normal knees rolled back to an average of -5.8 mm (range, -2.5 to -13.2 mm) whereas the meniscal bearing total knee replacements rolled back to -9.2 mm.
(range, −4 to −17 mm). From 60° to 90° flexion, normal knees continued to roll back to −7.8 mm (range, −5.8 to −13.8 mm), but the meniscal bearing total knee replacements slid anterior to −5 mm (range, 2 to −12 mm), (Fig 3). Qualitatively, the patterns of motion for normal knees were similar and individually were nearly reproducible. The meniscal bearing total knee replacement had variable patterns between patients, and consistently were less reproducible when looking at successive knee bends. Five of the meniscal bearing total knee replacements had anterior sliding of the bearings with flexion, whereas five bearing remained stationary in the same position relating to the tibial tray.

Passive and weightbearing ROM were significantly greater for normal knees compared with meniscal bearing total knee replacements. Decline in ROM seemed to be significantly greater for meniscal bearing total knee replacements compared with normal knees, from an average of 123° to 103° (Table 1).

Patellofemoral contact was similar between the normal knees and the meniscal bearing total knee replacements between 0° and 30°. Beyond 30°, this distance increased progressively for normal knees as the contact point moved superior on the patella. For meniscal bearing total knee replacements after 30°, the contact point tended to remain inferior and was erratic when comparing knees (Fig 4).

Patellar ligament rotation showed a consistent pattern of decrease for normal and meniscal bearing total knee replacements from 0° to 60° flexion. After 60°, the normal knees continued to decrease reflecting femoral rollback. Meniscal bearing total knee replacements,

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Fig 2. Kinematic relationships (β = patellar ligament angle; θ = patellar rotation angle; F = proximal tibial plateau midplane; CD = patellofemoral contact distance; BE = patella ligament; AB = longitudinal patella axis) See text for details.

however, had little change in the angle from 60° to 90°, possibly reflecting that the normal posterior movement of the ligament was negated by anterior tibiofemoral translation (Fig 5). Patellar rotation was similar to normal knees showing a steady increase from 0° to 90° flexion (Fig 6).

DISCUSSION
Posterior cruciate retention in total knee arthroplasty has been advocated as a means of preserving posterior femoral rollback based on the results of several cadaveric and gait studies.1,15,24,25 Andriacchi et al1 reported that the predominant shear force during gait and stair climbing is directed posterior on the tibia, which normally is resisted by the posterior cruciate ligament, preventing the anterior movement of the tibiofemoral contact point. Prior biomechanical studies consistently have shown a more posterior tibiofemoral contact position in full extension with anterior cruciate ligament deficient knees and those with posterior cruciate retaining total knee arthroplasty. This can be attributed in part to the unopposed ante-
Fig 4. Patellofemoral contact comparing the normal knee and the LCS mobile bearing patellar implant. (Patellofemoral contact is measured from the most anterior point of the tibial tray).

Fig 5. Patellar ligament rotation angle (β) comparing normal and the LCS mobile bearing patellar implant. (Patellar ligament rotation angle measures the angle between the patellar ligament and the longitudinal tibial axis.

Fig 6. Patellar rotation angle (θ) comparing normal and the LCS mobile bearing patellar implant. (Patellar rotation angle measures the angle between the patellar ligament and the longitudinal axis of the patella).

rior pull of the patellar tendon in lesser degrees of flexion. With increasing flexion, these studies have revealed a paradoxic anterior femoral translation in posterior cruciate retaining total knee arthroplasty if the posterior cruciate tension is inadequate.\textsuperscript{11,12,26} In vivo fluoroscopic studies have identified jerky cogwheel motion seen in some cases, the exaggerated amount of translation possible, and the fact that a specific knee will not have reproducible tibiofemoral contact curves as seen with normal knees.\textsuperscript{11,26}

The current study confirms that a meniscal bearing total knee replacement with posterior cruciate retention, at least kinematically, behaves similarly to other fixed bearing designs. Initial contact is posterior in extension, and beyond 60° flexion, there tends to be anterior tibiofemoral translation. Also, kinematic patterns beyond 60° flexion tend to be erratic and less reproducible compared with normal knees. Weightbearing ROM is significantly less than passive motion for the meniscal bearing total knee replacement. The average was 103° maximum flexion versus 123° measured passively. This could reflect anterior translation of tibiofemoral contact with progressive flexion, which may lead to earlier impingement of the posterior soft tissue structures and tightening of the extensor mechanism.

Meniscal bearing designs are unique from fixed bearings in that the mobile articulation of the underneath surface allows the creation of closely matched congruous interfaces over a significant ROM. The fully congruent components are expected to have improved wear through reduced contact stresses at the interfaces.\textsuperscript{2,7,9} Despite the kinematic abnor-
malities of the meniscal bearing total knee replacement in the current studies, this implant differed from fixed bearing total knee arthroplasties the authors have tested in that significant posterior femoral rollback was seen in the initial 40° flexion. This may reflect the high congruity noted with the LCS implant during early ROM.

Patellofemoral kinematics were poorly understood in posterior cruciate retaining total knee arthroplasty but video fluoroscopy has disclosed several interesting phenomena. The authors previously identified an extension clunk of the patellar articular surface against the distal femur with contraction of the extensor mechanism. With flexion, dome shaped patellar buttons tend to have a superior patellar contact compared with normal patellas giving the appearance of the patellofemoral articulation wedging open distally. Finally, the motion curves of prosthetic replacements were erratic and irreproducible compared with normal knees.26

Patellar ligament rotation in the normal knee reflects the relative anterior position of the normal patella in full extension.19,22 With increasing flexion this angle decreases as the patella follows the distal femur, which is rolling posteriorly. Patellar ligament rotation is altered in posterior cruciate ligament retaining total knee arthroplasty reflecting the posterior tibiofemoral starting position in extension followed by the tendency for anterior translation in deep flexion. The mobile bearing anatomic patellar design was more similar to a normal knee than was the fixed bearing total knee replacements; from 0° to 60° flexion reflecting the fact that some posterior femoral rollback occurs.26 In contrast to dome shaped button designs, patellofemoral contact for the mobile bearing patella was more inferior. This could be attributed to the higher congruity seen with this design. In deep flexion, mobile bearing patellas become erratic with some actually showing a steady increase in patella ligament rotation. This latter effect may be explained by the abnormal anterior tibiofemoral translation seen in deep flexion with the mobile bearing total knee arthroplasty.

This mobile bearing total knee replacement is comparable with other fixed bearing posterior cruciate retaining total knee replacements in that abnormal AP translation is present. This design differs from fixed bearing designs in that articular conformity is very high in full extension. This constraint may lead to early femoral rollback not seen typically in fixed bearing designs. Higher articular congruity is attractive for improved wear although this effect has not been proven conclusively at this time. Kinematics of the anatomic mobile bearing patella differs from other dome shaped designs in that patellofemoral contact remains inferior, possibly reflecting the high conformity of this design.

References


