Range of Motion After Total Knee Arthroplasty

The Effect of Implant Design and Weight-Bearing Conditions

Douglas A. Dennis, MD,* Richard D. Komistek, PhD,* James B. Stiehl, MD,† Scott A. Walker,* and Kendall N. Dennis*

Abstract: Knee range of motion was determined in 60 patients to assess the effect of weight bearing on maximal knee flexion. Three patient subgroups were investigated: patients with normal knees, patients implanted with posterior cruciate-retaining (PCR) total knee arthroplasty (TKA), and patients implanted with posterior cruciate-substituting (PS) TKA. Maximal knee flexion was determined using videofluoroscopy both in a passive, non-weight-bearing mode and during active weight bearing. Flexion was diminished with weight bearing in all three subgroups (P < .045). Patients with normal knees exhibited significantly greater knee flexion than either TKA subgroup when measured either with or without weight bearing (P < .001). Knee flexion of both TKA subgroups was similar when measured passively without weight bearing. Patients with PS TKA demonstrated greater flexion than patients with PCR TKA when measured in weight bearing (P < .025), despite having less range of motion and lower clinical performance ratings preoperatively. Measurement of knee range of motion in a weight-bearing fashion may be a superior method of assessment of functional capabilities. Key words: knee prosthesis, range of motion, prosthesis design, fluoroscopy.

Satisfactory postoperative range of motion is an important component of successful total knee arthroplasty (TKA). By using electrogoniometric measurements in weight-bearing patients, it has been shown that 67° of flexion are required for the swing phase of gait, 83° to climb stairs, 90° to descend stairs, and at least 93° to rise from a chair [1,2]. Outcome studies have investigated various techniques and prosthetic types and have shown little difference in functional outcome or motion [3]. A metaanalysis comparing data from 57 studies published between 1973 and 1992 showed a mean improvement of 8° in postoperative range of motion after TKA. The best range of motion was reported in posterior cruciate-retaining (PCR) implants (mean, 106.8°), which was greater than posterior cruciate-substituting (PS) implants (mean, 103.1°) and significantly greater (P < .05) than posterior cruciate-sacrificing implants (mean, 98.3°) [4]. Based on a review of the literature, we presume that virtually all clinical series have used passive and non-weight-bearing range of motion methods for clinical assessment.

The purpose of this study was to determine the effect of weight bearing on range of motion in patients with normal knee function and in patients with TKA implants. Additionally, we assessed if weight-bearing range of motion was affected by implant type, that is, PCR versus posterior cruciate-substituting (PS) TKA implants of a similar prosthetic design.

Materials and Methods

Knee range of motion of 60 patients was evaluated using videofluoroscopy. Three patient sub-
groups were separately analyzed and compared: those with clinically normal knees (20 patients), those who received implants of a PCR TKA (20 patients), and those who received implants of a PS TKA (20 patients). Patients evaluated with nonimplanted knees were randomly selected on the basis of the following criteria: (1) no reported knee pain, functional limitation related to the knee, or previous injury; and (2) clinical examination indicating no measurable ligamentous instability.

All patients in both TKA subgroups selected were considered clinically successful without significant pain or measurable ligamentous instability and clinical rating scores categorized as excellent. The minimal postoperative follow-up of all patients was 1 year. Preoperative clinical assessment included passive, non-weight-bearing range of motion and Hospital for Special Surgery (HSS) knee rating scores [5]. There were no statistically significant differences in preoperative range of motion, preoperative or postoperative HSS knee rating scores, patient age, or body weight between the two TKA subgroups (this could be found using a two-sample unequal variance Student’s t-test). Additional patient demographic data are given in Table 1.

All total knee components were implanted by a single surgeon (D.A.D.) using a standardized technique with prosthetic components with similar geometric dimensions for either posterior cruciate ligament retention or substitution (Press-Fit Condylar, Johnson and Johnson, Inc., Raynham, MA). The type of PCR tibial insert used was unconstrained with minimal conformity (posterior lip design). Based on previous biomechanical analyses, this design was believed to be theoretically advantageous if posterior femoral rollback was to be accommodated without posterior impingement, or the kinetic conflict [6]. The femoral and tibial components had nearly identical geometry except for the femoral intercondylar box and tibial insert post for the PS design. The patella was prosthetically resurfaced in all patients of both TKA subgroups.

All patients were examined with a VF Works Dynamic Motion x-ray image intensifier (VF Works, Inc., Palm Harbor, FL). Each patient performed three successive weight-bearing deep knee bends to the maximal flexion attainable (Fig. 1). Subsequently, passive non-weight-bearing range of motion was determined by having an erect standing patient raise the foot from the ground to maximal knee flexion. To ensure maximal passive knee flexion, subjects were allowed to assist by grasping and pulling their foot superiorly (Fig. 2). Preoperative range of motion in both TKA subgroups was measured in a standard fashion in a non-weight-bearing mode using a hand-held goniometer. Using a video capture board, the fluoroscopically obtained videotapes were then analyzed digitally on a computer workstation by applying Khoros image analysis and display software (Koral Research, Albuquerque, NM).

To ensure accurate assessment, the maximal range of motion for each subject was determined using a digitization technique previously described for fluoroscopic studies [7]. Points F1 through F4 on the femur and T1 through T4 on the tibia were located and digitized (Fig. 3). Lines were then constructed on the fluoroscopic images from points F1 to F2, F3 to F4, T1 to T2, and T3 to T4. On measuring the length of each line, the midpoints were located and denoted as points F5 through F8 and T5 through T8. The longitudinal axes of the femur and the tibia were derived by constructing lines through points F3 and F4 and points T3 and T4. The angle between the longitudinal axes was...
measured digitally to 0.1° and denoted as the maximal range of motion. Statistical analyses of patient subgroup and testing method comparisons were performed using a two-tailed distribution, two-sample unequal variance Student’s t-test.

Results

Results of knee range-of-motion measurements and statistical analysis data are summarized in Tables 2, 3, and 4. All three knee subgroups demonstrated a statistically significant decline in range of motion when measured during weight bearing as compared with non-weight bearing (normal, \( P < .045 \); PS, \( P < .001 \); PCR, \( P < .001 \)). This reduction in motion was greatest in the PCR TKA subgroup (20° reduction). The normal knee subgroup exhibited superior flexion over either TKA subgroup, whether measured under passive non-weight-bearing \((P < .001)\) or active weight-bearing conditions \((P < .001)\). Maximal mean postoperative flexion for PCR (123°) and PS (127°) TKA subgroups was similar when evaluated under passive non-weight-bearing conditions \((P > .176)\). When measured under weight-bearing conditions, patients implanted with PS TKA exhibited significantly greater mean range of motion than those with PCR TKA (113° vs 103°, \( P < .024 \)). This finding occurred despite the fact that the PCR subgroup demonstrated greater knee flexion (118° vs 108°) and had higher HSS scores (65.2 points vs 58.7 points) than the PS subgroup preoperatively and also were of younger age (53.7 years vs 65.5 years), although these differences were not significant statistically. No significant differences in knee range of motion related to gender were observed in any subgroup or testing condition \((P < .01)\).

Discussion

This study involved the investigation of knee range-of-motion in patients with normal and prosthetically implanted knees to assess the effect of weight bearing and prosthetic design. A previous evaluation of TKA has indicated that weight-bearing flexion was less than with passive non-weight-bearing methods, but documentation of preoperative status was unavailable, and most patients had only a PCR prosthesis. The maximal weight-bearing flexion of any PCR TKA in this evaluation was only 98° [8].
joint laxity is primarily determined by soft tissue primary determinant in controlling knee joint lax-

geometric conformity of the joint surfaces is the weight bearing in kinematic evaluation of the knee bearing articulated motion. The importance of constraints, whereas in the loaded knee joint, the least resistance and may not reflect normal weight-

constraints, posterior soft tissue impingement, and interaction of dynamic muscle forces, soft tissue motion was significantly diminished in all of our subjects, presumably resulting from the complex interaction of dynamic muscle forces, soft tissue constraints, posterior soft tissue impingement, and articular congruity. Under passive non-weight-bearing conditions, the knee seeks the course of least resistance and may not reflect normal weight-bearing articulated motion. The importance of weight bearing in kinematic evaluation of the knee is supported by the work of Hsieh and Walker [13], who determined that in the unloaded knee joint, joint laxity is primarily determined by soft tissue constraints, whereas in the loaded knee joint, the geometric conformity of the joint surfaces is the primary determinant in controlling knee joint lax-

Most previously published studies have failed to demonstrate superiority of any specific treatment method of the posterior cruciate ligament with retention, sacrifice, or substitution in regards to range of motion [9–11]. Dorr et al. [9] evaluated the functional outcome in bilateral-paired PCR and cruciate-sacrificing (nonsubstituting) TKA and found similar motion with both gait analysis and passive flexion. Becker et al. [10] evaluated bilateral-paired PCR and PS TKA and could find no difference in postoperative motion, with 111° average flexion for PCR TKA and 112.6° for PS TKA. Maloney and Schurman [11] compared the results of a PS device with a posterior cruciate-sacrificing design and could find no statistical difference in gain of range of motion under passive conditions. Similarly, our results failed to show a difference between patients implanted with PCR or PS TKA when assessed under passive, non-weight-bearing conditions. Hirsch et al. [12], in their review of 242 cases of primary TKA, observed superior range of motion with PS TKA (112°) than in patients implanted with either posterior cruciate sacrificing (103°) or preserving (104°) TKA (P = .001). Weight-bearing range of motion was significantly diminished in all of our subjects, presumably resulting from the complex interaction of dynamic muscle forces, soft tissue constraints, posterior soft tissue impingement, and articular congruity. Under passive non-weight-bearing conditions, the knee seeks the course of least resistance and may not reflect normal weight-bearing articulated motion. The importance of weight bearing in kinematic evaluation of the knee is supported by the work of Hsieh and Walker [13], who determined that in the unloaded knee joint, joint laxity is primarily determined by soft tissue constraints, whereas in the loaded knee joint, the geometric conformity of the joint surfaces is the primary determinant in controlling knee joint lax-

ity. When tested under weight-bearing conditions, patients with PCR TKA exhibited significantly lower postoperative motion than those with PS TKA, despite the fact that those patients were younger with better preoperative range of motion and higher preoperative functional scores (nonstatistically significant differences).

Several in vivo kinematic studies of TKA have found that posterior femoral rollback is not a predict-

able phenomenon in the knees of patients implanted with PCR TKA [7,8,14–21]. By contrast, the femorotibial contact position in extension is drawn posteriorly. This has been attributed, in part, to the absence of the anterior cruciate ligament, excessive tension in the posterior cruciate ligament, and anteriorly directed pull of the patellar ligament on the tibia within this range of knee flexion [7,17,22–25]. With knee flexion, anterior translation of the femur on the tibia has been observed, creating a kinematic pathway opposite that displayed by the normal knee joint. This anterior translation of femorotibial contact with progressive flexion may limit maximal flexion because of anteriorization of the axis of flexion, earlier impingement of the posterior soft tissue structures, and tightening of the extensor mechanism (from anterior femoral displacement). Alternatively, patients implanted with PS TKA demonstrate posterior femoral rollback dictated by interaction of the femoral cam and tibial post mechanism of the posterior cruciate substituting design, regardless of weight-bearing status [7]. These kinematic differences may account for the significant loss of weight-bearing range of motion with PCR TKA observed in this study. Because a substantial portion of activities of daily living are performed by subjects under weight-bearing conditions, measurement of knee motion in a weight-bearing fashion may be a superior method of assessment of functional capabili-

Table 4. Subgroup Statistical Analysis (Student t-Test)

<table>
<thead>
<tr>
<th>Subgroup Comparison</th>
<th>Weight-Bearing Status</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal vs PCR TKA</td>
<td>Passive/non-weight</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Normal vs PCR TKA</td>
<td>Active/weight bearing</td>
<td>&lt;.001</td>
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<tr>
<td>Normal vs PS TKA</td>
<td>Passive/non-weight</td>
<td>&lt;.001</td>
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<tr>
<td>Normal vs PS TKA</td>
<td>Active/weight bearing</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>PS vs PCR TKA</td>
<td>Passive/non-weight</td>
<td>&gt;.176</td>
</tr>
<tr>
<td>PS vs PCR TKA</td>
<td>Active/weight bearing</td>
<td>&lt;.024</td>
</tr>
</tbody>
</table>

PCR TKA, posterior cruciate-retaining total knee arthroplasty; PS TKA, posterior cruciate-substituting total knee arthroplasty.

Conclusion

This study has identified that weight-bearing range of motion is diminished when compared to passive non-weight-bearing range of motion in patients both with normal knees and after TKA. Subjects with normal knees exhibited greater knee flexion than those implanted with TKA. Passive, non-weight-bearing, postoperative flexion was similar for both PCR or PS TKA designs. Under weight-bearing conditions, subjects with PCR TKA demonstrated significantly less postoperative flexion despite being done in younger patients with higher preop-
ervative knee flexion and higher preoperative HSS scores. This phenomenon may, in part, be secondary to anterior translation of femorotibial contact position with progressive knee flexion observed in some in vivo, weight-bearing kinematic analyses [2,7,8,17].

References