In vivo kinematics of total knee arthroplasty

CONCA VE VERSUS POSTERIOR-STABILISED TIBIAL JOINT SURFACE

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We studied the kinetics of the knee in 20 patients (22 knees) 12 months after total knee arthroplasty (TKA), by using three-dimensional radiostereometry and film-exchanger techniques. Eleven knees had a concave (constrained) tibial implant and 11 a posterior-stabilised prosthesis. Eleven normal knees served as a control group.

In the posterior-stabilised knees there was less proximal and posterior displacement of the centre of the tibial plateau during extension from 45° to 15°, with a decrease in the anterior translation of the femoral condyles of 4 mm at 45°. There was less internal tibial rotation and increased distal positioning of the centre of the tibial plateau with both designs when compared with the normal knees, and in both the centre of the plateau was displaced posteriorly by more than 1 cm.

Increased AP translation has been recorded in all prosthetic designs so far studied by radiostereometry. The use of a posterior-stabilised design of tibial insert could reduce this translation but not to that of the normal knee.

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The kinetics of total knee arthroplasty (TKA) have a complex influence on its performance, and differing abnormal patterns have been shown after TKA using gait analysis,1-6 fluoroscopy7-11 and radiostereometry.12-15 Several studies9,13,14,16 have related variations in these abnormalities to the design of the articulating surfaces. All of the seven designs studied by radiostereometry have shown increased anteroposterior (AP) translation and most demonstrated abnormal rotation when compared with normal knees.

Some studies have indicated that retention of the posterior cruciate ligament (PCL) increases prosthetic translation with a higher incidence of wear of the polyethylene component.8,9,17,18 If the PCL is resected substitution with a posterior-stabilised (PS) design may be carried out but translation and gait may not be restored.5,8,9 We compared the kinetics of a concave with those of a PS insert one year after operation using radiostereometry to determine whether the use of a PS design with a central post results in less translation and rotation.

Patients and Methods

We studied 22 knees in 20 patients (11 men and nine women) with a mean age of 70 years (53 to 81) who had degenerative arthritis of the knee. They all had varus or valgus deformities of more than 5° and/or fixed flexion deformities of more than 10°. The AMK (DePuy) TKA was used. The patients were divided into two groups, 11 receiving a constrained (C) insert and 11 a PS implant (Fig. 1). Two patients studied bilaterally had different implants on the two sides. Table I gives their clinical details. The normal knees of 11 patients with a tear of the anterior cruciate ligament on the opposite side were used as a control group. There were eight women and three men with a mean age of 25 years (18 to 41). The normal knees were marked with tantalum pellets for comparison with the injured side.

Spinal or epidural anaesthesia and a tourniquet were used. The knee was approached medially through a standard anterior incision. The PCL was resected. Six to nine spherical tantalum markers, measuring 0.8 mm, were inserted into the distal femur and the proximal tibia before the introduction of the components. Routine mobilisation began on the first day after operation.

One year after operation we studied the kinetics of the knee during extension when ascending a platform 8 cm high. Before this, a reference position was determined when the knee was aligned with the co-ordinate axes of a Plexiglas calibration cage with the patient supine and the joint extended.19 Stereographic studies were performed using simultaneous and sequential exposures (3 to 4/s) from ceiling-mounted x-ray tubes. We constructed a recording unit (Fig. 2) with two film exchangers mounted on a frame.
which allowed adjustment of the height and angle between them. Reference plates and a separate calibration system were used to allow unrestricted movement of the knee. Each examination generated 6 to 14 pairs of radiographs with movement corresponding to 1.5 to 4 s of activity.

Rotation and translation were presented as previously described. Thus, tibial translation was measured at the centre of the knee using the markers in the distal femur as reference. In the normal knees a point between the two tips of the tibial intercondylar eminence was used when measuring translation. We also recorded the translation of a point at the centre of a circle described by the projection of the posterior aspect of the femoral condyles. The tibial markers were used as a reference point for this analysis of translation of the femoral condyles. At the reference examination the AP position of the tibia in relation to the femur was measured as described by Nilsson et al.\textsuperscript{13} The position of the tibial component was recorded by measuring its angle (PT-angle) on the AP radiograph and its sagittal angle (PTS-angle) on the lateral radiograph as described by Albrektsson and Herberts.\textsuperscript{24} The position of the femoral component was recorded by measuring the femoral angle on the AP view (Fig. 3).

We used the Hospital for Special Surgery knee score (HSS) for evaluation.\textsuperscript{25} The patients were also asked if they had symptoms of instability and if they regarded their knee function as normal, almost normal or abnormal (Table I).

**Statistical analysis.** We used repeated-measures ANOVA (MANOVA) to compare the three groups. This was done in the interval of 45° to 15° when observations from all 33 patients were available. A p value of less than 0.025 was significant. The graphs represent the mean and the SEM and the median values and ranges are presented at 45° of flexion. The Mann-Whitney U test was used to compare the clinical outcome including the HSS score.

Evaluation of a possible association between the positions of the components and the observed kinetics was only recorded at 45° of flexion using non-parametric correlation (Spearman’s rho).

**Results**

There was a median extension from 53° (45 to 63) to 5° (-10 to +15) after TKA and from 59° (50 to 70) to -5° (-14 to +15) in the control group.

**Tibial rotation** (Table II). From a position of slight internally rotated at 45° of flexion the tibia rotated externally during extension (Fig. 4) with no difference between the two inserts (C v PS, p = 0.3). There was more internal rotation of the tibia throughout the range of extension in the control group (C v N, p = 0.008; PS v N, p = 0.001). The
mean varus-valgus angle was small in all three groups with no significant difference (Fig. 5, C v PS, p = 0.8; C v N, PS v N, p > 0.6).

**Tibial translation** (Table II). The mean mediolateral translation of the centre of the tibial plateau was up to 1.5 mm, with no difference between the groups (Fig. 6, C v PS, p = 0.2; C v N, p = 0.7; PS v N, p = 0.07).

Table I. Details of the patients, HSS scores and patients' opinion regarding their knee

<table>
<thead>
<tr>
<th>Type of knees</th>
<th>Concave</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of knees</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Median age in years (range)</td>
<td>71 (60 to 80)</td>
<td>69 (53 to 81)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Type of arthritis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Lateral</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Median HSS score (range)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preop</td>
<td>59 (49 to 70)</td>
<td>59 (42 to 79)</td>
</tr>
<tr>
<td>1 year</td>
<td>84 (71 to 96)</td>
<td>83 (61 to 95)</td>
</tr>
<tr>
<td>Difference 0 to 1 year</td>
<td>25 (9 to 33)</td>
<td>24 (6 to 43)</td>
</tr>
<tr>
<td>Feeling of instability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>No</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Normality of the knee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Almost</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>No</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

The centre of the tibial plateau displaced distally with increasing extension from 45°. The PS design followed a more distal path during extension between 45° and 15° than the constrained insert (Fig. 7, C v PS, p = 0.025) and both had a more distal path than the normal group (C v N, p = 0.001; PS v N, p = 0.005).

Flexion of the knee resulted in posterior displacement of the centre of the tibia (Fig. 8), which was more pronounced in the TKAs with constrained inserts (C v PS, p = 0.002). At 45° these inserts had displaced 18 mm and the PS implants 11 mm more posteriorly than the normal knees (C v N, PS v N, p < 0.0005).

**AP translation of the femur.** For this analysis the translation of the central point of the femur with reference to the stationary tibial marker was recorded, and was found to lie anteriorly in the TKA group. The anterior displacement decreased with increasing extension. The constrained design was associated with more anterior displacement than the PS design (C v PS, p = 0.003). At 45° the mean anterior displacement of this point was 11.4 mm and was 6.5 mm more in the TKA groups than in the normal knees. The differences in movement between 45° and 15° seen in the TKA groups compared with control knees were significant.
(Fig. 9, N v C, N v PS p < 0.0005). Contrary to the findings in the knees with TKA the change of the condylar position in the normal knees was much less with the increasing extension (approximately 1 mm).

Relative position of the tibia in extension. There was a wider variation in the relative position of the tibia in the prosthetic groups, and it lay more anteriorly (Table III, C v PS, p = 0.9; C v N, p = 0.002; PS v N, p = 0.008).

Coupled movements at 45° of flexion. In both prosthetic groups varus angulation was associated with medial displacement and valgus angulation with lateral displacement of the centre of the tibial plateau (C, rho = 0.80, p = 0.003; PS, rho = 0.85, p = 0.001). In normal knees the correlation coefficient was smaller and did not reach significance (rho = 0.51, p = 0.11).

Position of the prosthetic components in relation to the joint position at 45° of flexion. In the constrained group there was a relation between the slope of the tibial component on the lateral view and the AP translation of the centre of the tibial plateau. The more posterior the tilt of the plateau the smaller was the posterior translation (rho = 0.76, p = 0.006).
Clinical results. The clinical results did not differ between the prosthetic groups (Table I). One patient with a unilateral prosthesis (PS) experienced occasional instability. Four (1C, 3PS) reported normal function whereas 13 (7 C, 6 PS) regarded their knee as almost normal and five (3C, 2PS) reported function that was definitely abnormal. There was no association between the patients’ opinion of their knee and relative tibial movement at 45° of flexion.

Discussion

There have been several reports concerning the resection of the PCL during TKA and the use of PS designs.\(^1\)\(^8\)\(^{26}\)\(^{27}\) Li et al\(^{26}\) suggested that retention of the PCL increases the range of movement, stability and proprioception and reduces wear of polyethylene. Andriacchi et al\(^1\) and Andriacchi and Galante\(^{28}\) reported better gait and knee function when using a PCL-retaining prosthesis, and Wilson et al\(^5\) also reported better gait with prostheses of a design which retained the PCL or included a function which allowed for substitution of its function should resection be necessary. Dorr et al\(^{29}\) noted increased medial loading after resection of the PCL in TKA. Bolanos et al\(^2\) suggested that a PS design was effective as a substitution for the PCL. Satisfactory results have been widely reported for PS TKAs,\(^{30}\)\(^{33}\) although Insall et al\(^{32}\) reported increased patellar problems with this design.

In our study the range of movement did not differ between the two designs and this has previously been reported by Maloney and Schurman.\(^{34}\) Stiehl et al\(^{35}\) recorded a mean rotation of 0.5° at the limit of extension in cruciate-sacrificing LCS prostheses with a rotating platform. There was a wide scatter from about 10° of internal rotation to 6° of external rotation. By comparison with our previous study of the AMK prosthesis,\(^{16}\) we did not find reduced tibial rotation during extension associated with increased restraint. Thus the configuration of the joint and the presence or absence of the PCL has little effect on tibial rotation during extension of the knee. Banks et al\(^{11}\) however, have studied three different designs and found that
rotation and translation were reduced when the PCL was resected or substituted.

Those who favour resection of the PCL\textsuperscript{11,18,36-38} argue that this will facilitate balancing the soft tissues especially with significant varus or valgus deformity.\textsuperscript{18,38,39} We have previously found that knees with an intact PCL displayed slight valgus angulation and lateral translation in the flexed position. The corresponding design in this study without a PCL showed varus angulation and medial translation. These findings support the observations of Dorr et al.\textsuperscript{30} who noted that the limit of abduction decreased when the PCL was preserved in the cadaver knee. Our findings support the view that the PCL has an effect on ligament balance in the prosthetic knee, but not, as expected, on AP translation. Its influence seems to be restricted to medial/lateral or adduction/abduction stability.

According to Stiehl et al.\textsuperscript{35,41} medial or lateral condylar lift-off commonly occurs with some designs of TKA. This could be caused by medial or lateral instability, or subluxation of a femoral condyle as it moves along the sloping edge of a concave insert with axial rotation.

Incavo et al.\textsuperscript{12} compared different tibial designs with and without substitution of the PCL in cadaver knees and found that none of the TKAs restored normal kinetics, as was noted by us in this study. The use of a PS design, however, had a significant effect on AP tibiofemoral translation. The difference between the groups could be caused partly by absence of the PCL in the group with a concave tibial insert. Our previous studies of the same implant without resection of the PCL do, however, suggest the reverse. The mean AP translation of AMK prostheses with retention of the PCL was almost identical to that found in the present study. The most likely explanation for this finding is that the PCL does not restrain AP translation after insertion of a TKA. Similar observations have been made with other PCL-retaining designs.\textsuperscript{13,14} The reason for this finding is unclear. Hirsch, Lotke and Morrison\textsuperscript{43} suggested that the PCL, when retained, does not necessarily improve the function of the TKA. Insall\textsuperscript{13} stated that placing exact tension on the PCL is often difficult and depends largely on luck. It seems that alterations of kinematics and load distribution across the knee caused by the anatomy of the artificial joint and resection of the anterior cruciate ligament, will unload the PCL and make it less efficient at countereacting anterior femoral displacement. The increased AP translation shows small variations and can only marginally be affected by the optimum insertion of the implant and ligament balancing. Thus, the PCL does not seem to play a major role in the control of the degree of AP translation in many designs of TKA.

In summary, the use of a central post stabilised the knee, but only in the AP direction. Despite this the AP translation was still abnormal. The optimum kinetics required of a knee prosthesis remain unclear.

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\textbf{References}

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