Fluoroscopic analysis of the kinematics of deep flexion in total knee arthroplasty

INFLUENCE OF POSTERIOR CONDYLAR OFFSET

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Our purpose was to determine the mechanism which allows the maximum knee flexion in vivo after a posterior-cruciate-ligament (PCL)-retaining total knee arthroplasty.

Using three-dimensional computer-aided design videofluoroscopy of deep squatting in 29 patients, we determined that in 72% of knees, direct impingement of the tibial insert posteriorly against the back of the femur was the factor responsible for blocking further flexion.

In view of this finding we defined a new parameter termed the 'posterior condylar offset'. In 150 consecutive arthroplasties of the knee, the magnitude of posterior condylar offset was found to correlate with the final range of flexion.

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Total knee arthroplasty (TKA) gives good subjective and objective results during the first 15 years after implantation. Nevertheless, it is clear that the function and subjective findings do not match those of the normal knee. The range of flexion of the knee obtained after TKA is often limited and may be determined by several factors, including the length of the quadriceps, capsular tightness, surgical technique, postoperative physiotherapy and the design of the implant.^{1,2}

Our aim was to identify the factors limiting the range of active flexion after TKA and to compare our findings with

those obtained in a larger group of 150 consecutive patients who had undergone primary posterior-cruciate-ligament (PCL)-retaining TKA.

Patients and Methods

Our study consisted of two parts. First, 30 patients who had previously undergone a PCL-retaining TKA were selected from our patient database. The criteria for inclusion were a preoperative diagnosis of end-stage osteoarthritis of the knee which had been operated on one to two years before our study with a good or excellent postoperative result (i.e., a knee score of 90 or more and a function score of 80 or more, according to the Knee Society Scoring System³), and a final range of flexion of at least 100°. Patients with rheumatoid arthritis, post-traumatic or postinfectious osteoarthritis were excluded. Each of the 30 patients gave informed consent for fluoroscopic examination.

The patients were asked to do a number of consecutive active knee squats with maximal knee flexion under video-fluoroscopic imaging using a 30 cm image intensifier and a 10 ms pulsed x-ray beam (OEC 9800 Cardiac, GE OEC, Salt Lake City, Utah). After digitising, the exact kinematic pattern of movement was determined by three-dimensional superposition of the implanted components using the appropriate 3D-computer-aided design models as described previously.⁴ The anteroposterior position of the femoro-tibial contact point both in the medial and lateral compartment, overall femorotibial rotation, and the centre of axial rotation were continuously recorded through the entire range of movement until the maximal flexion during the squatting manoeuvre was achieved. In deep flexion, observations were directed towards potential areas of kinematic conflict, for example, bone-implant impingement and patello-femoral tracking.

In the second part, we studied 150 consecutive patients who had undergone a PCL-retaining TKA for primary osteoarthritis of the knee. All had been operated on between two and five years before this study by the same surgeon (JB) and using the same implant (Profix; Smith and Nephew). In all knees the same surgical technique was followed, using standard intramedullary alignment blocks, standard ligament-balancing techniques, an anterior femoral referencing system, and a constant tibial articular slope

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Fig. 1

Diagram showing the measurement of posterior condylar offset (A) before and (B) after operation.

Fig. 2

Typical videofluoroscopic capture of a patient in a deep squat showing impingement of the tibial insert posteriorly against the femoral bone.

of 3° . The postoperative range of flexion was measured as well as the 'posterior condylar offset'. The range of movement was determined using standard (38 cm) clinical goniometers before operation and at review. Preoperative and postoperative posterior condylar offset was evaluated on true lateral radiographs by measuring the maximal thickness of the posterior condyle, projected posteriorly to the tangent of the posterior cortex of the femoral shaft (Fig. 1). The preoperative and postoperative measurements were then compared, after correction for magnification, using a

reference measurement of the diameter of the femoral shaft 10 cm proximal to the femoral articular surface. Measurements were analysed statistically using Pearson's regression analysis and the independent unpaired Student *t*-test.

Results

In the first part of the study, videofluoroscopic data of high quality were obtained in 29 of the 30 patients. Grossly aberrant kinematics were observed in most knees. In 27 patients, forward slide of the femur was noted during flexion, with anterior translation of the medial and/or lateral femorotibial contact position. The mean overall translation for the medial femorotibial contact point was 1.97 mm anteriorly (SD 4.46), and for the lateral contact point 0.27 mm anteriorly (SD 5.46) from extension to maximal flexion. In only two knees did we observe the normal kinematic pattern with asymmetrical, predominantly lateral femoral posterior displacement. From extension to maximal flexion an overall mean internal tibial rotation of 2.7° (SD 7.9) was recorded.

In deep squat, the mean maximal flexion angle achieved was 121.7° (SD 12.3) using a goniometer, but when this was measured on the digitised videofluoroscopic images a mean of 117.3° (SD 12.4) was noted. Also in the deep squat, impingement of the posterior aspect of the tibial insert against the shaft of the femur was noted in 21 knees (72.4%). In 19 of these direct contact against the back of the femur was observed both by the posteromedial and posterolateral part of the tibial insert, while in three only the posteromedial part impinged against the bone. In none of these 21 patients did a further increase in flexion occur once contact between the insert and the femoral bone had been made (Fig. 2).

In the second part of our study the mean preoperative range of movement of the 150 patients was 105.0° (SD 20.2) and the postoperative range of movement, 105.9° (SD 17.3). Postoperative evaluation was not obtained in eight knees, and these patients were replaced by the next eight from the database. The mean preoperative posterior condylar offset was 25.8 mm (SD 2.9); after operation it measured 23.6 mm (SD 3.8). The decreased postoperative posterior condylar offset correlated with a decreased final maximal flexion ($R^2 = 0.58$, $p < 0.001$). For every millimetre lost in posterior condylar offset compared with the preoperative finding the maximal final flexion was reduced by a mean of 6.1° (Fig. 3). Patients with a reduction of 3 mm or more in posterior condylar offset had a mean of 29.7° less maximal flexion after operation compared with those in whom the preoperative posterior condylar offset was restored to within 3 mm ($p < 0.001$).

Discussion

Using videofluoroscopy we have shown that in 72% of the knees investigated the maximal degree of active flexion

Fig. 3

Correlation of restoration of posterior condylar offset (postoperative minus preoperative) with postoperative flexion gain(+)/loss(-). Overlapping points are not shown.

Fig. 4

Diagram showing that decreased posterior condylar offset (left) leads to earlier impingement and limited flexion ($x < x'$).

was determined by direct impingement of the posterior aspect of the tibial insert against the posterior aspect of the femur.

All patients in our study enjoyed good to excellent subjective and objective postoperative results according to established scoring methods, and were selected especially for the purpose of determining the factor responsible for limiting the achievable flexion after PCL-retaining TKA. A mechanical block caused by impingement is shown by the kinematic pattern observed in these patients, with (paradoxical) forward sliding of the femur during flexion (in 93% of patients). This type of paradoxical femoral roll-forward with flexion has been noted previously in PCL-retaining knees by other investigators.⁴⁻⁸ The inability to maintain or restore a functional PCL with the current instrumentation and prosthetic designs is believed to be the cause of this paradoxical pattern.

The patients in our study were operated on by an experienced surgical team using the latest instrumentation, a modern design of prosthesis and established ligament-balancing techniques. Even under these conditions, more than 90% of the knees showed aberrant kinematics. It has been debated whether it is important to reproduce the

normal kinematics of the knee which have been described as an asymmetrical femoral roll-back pattern, predominantly on the lateral side.⁹⁻¹² Our study shows that failure to reproduce this normal pattern is a direct cause of posterior impingement and a mechanical block of flexion in contemporary PCL-retaining designs of implant.

Two other factors may contribute; the presence of a high posterior lip on the tibial polyethylene insert and an insufficient posterior slope to the tibial cut, which has the same effect as a high posterior lip. Our observations in the fluoroscopy study led us to assume that increasing the 'posterior condylar offset' may be associated with a greater range of obtainable flexion, if it avoids impingement during increased flexion (Fig. 4).

This hypothesis was investigated and confirmed in the second part of our study. A significant correlation was shown between operative restoration of posterior condylar offset and maximal flexion. The more posterior condylar offset was decreased after operation the more flexion was lost. For every 2 mm decrease in posterior condylar offset, the maximal obtainable flexion was reduced by a mean of 12.2°. Restoration of posterior condylar offset is therefore recommended in PCL-retaining TKA. Using anterior referencing instrumentation, this is, however, rarely achieved. Operative technical guides which use anterior referencing usually suggest the use of a smaller femoral component. By downsizing, overfilling of the flexion space with prosthetic material is avoided, and flexion is believed to be facilitated by greater laxity. Our study, however, does not confirm this reasoning. As well as risking an excessive flexion gap, downsizing with anterior referencing leads to a decreased posterior condylar offset and therefore to reduced flexion because of earlier impingement.

Nakagawa et al¹¹ have shown that, in the normal knee, full flexion is also accompanied by impingement between the posterior femur and the posterior horn of the medial meniscus. They have demonstrated that the meniscal horn is squeezed between the femur and the tibia, acting as a fulcrum and lifting the femoral condyle from the tibial surface, thereby tending to sublux the joint. Not only are

the mechanisms essentially similar, but it may be argued that if the normal joint does this beyond 120° flexion, a similar mechanism is required in a prosthetic knee.

We conclude that in most cases, the maximal obtainable flexion in vivo with a modern PCL-retaining TKA, is ultimately determined by impingement of the posterior tibial insert against the femur, and this is exaggerated as a result of aberrant kinematics with anterior sliding of the femur during flexion. Restoration of posterior condylar offset is therefore important, since it allows a greater degree of flexion before impingement occurs.

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