Evaluation of impingement of the anterior tibial post during gait in a posteriorly-stabilised total knee replacement


From Kyushu University, Fukuoka, Japan

Mechanical failure because of wear or fracture of the polyethylene tibial post in posteriorly-stabilised total knee replacements has been extensively described. In this study of 12 patients with a clinically and radiologically successful NexGen LPS posteriorly-stabilised prosthesis impingement of the anterior tibial post was evaluated in vivo in three dimensions during gait using radiologically-based image-matching techniques.

Impingement was observed in all images of the patients during the stance phase, although the NexGen LPS was designed to accommodate 14° of hyperextension of the component before impingement occurred. Impingement arises as a result of posterior translation of the femur during the stance phase. Further attention must therefore be given to the configuration of the anterior portion of the femoral component and the polyethylene post when designing posteriorly-stabilised total knee replacements.

Kinematic analysis of many designs of total knee replacement (TKR) with subjects performing various functional activities is now available.1-8 Most of these fluoroscopic studies have focused on the movement of the femoral component relative to the tibial tray. There is very little information about the relative movement between the femoral component and the polyethylene tibial insert, especially regarding impingement of the anterior post. Patients with a TKR may extend their knees during gait,9 with contact of the anterior tibial post.10

Flexion of the femoral component and/or the posterior tibial slope allow impingement of the femoral cam on the anterior aspect of the tibial post.9-13 However, in many cases with severe wear or fracture of the tibial post, no specific malposition or malalignment of either the femoral or the tibial components could be identified.13-15 Without relative hyperextension of the implant, posterior translation of the femur relative to the tibia could result in impingement against the anterior post. The position of the femur relative to the tibia near full extension is determined by the surface geometry of the articular components, the cam-post mechanism, and the quadriceps force under weight-bearing conditions.16 The tibial post may function as a substitute for the anterior cruciate ligament (ACL) by providing anterior stability of the knee in low degrees of flexion.

The main purpose of this study was to determine whether the intercondylar notch of the femoral component impinges on the anterior aspect of the tibial post during gait with a posteriorly-stabilised TKR using high-resolution dynamic flat-panel detector images. The secondary purpose was to observe whether there was a correlation between the sagittal alignment of knee prostheses and the impingement on the anterior post under dynamic weight-bearing conditions.

Patients and Methods

A total of 12 patients who had a good outcome following TKR were included in the study following informed consent and approval from the institutional review board. There were two men and ten women with a mean age of 73 years (67 to 86). Their mean height was 149 cm (137 to 157) and their mean weight was 62 kg (45 to 71). The mean pre-operative extension of the knee was -10° (-25° to 0°) and the mean pre-operative flexion was 110° (25° to 130°). The pre-operative diagnosis was osteoarthritis in seven knees and rheumatoid arthritis in five. All the patients received a posteriorly-stabilised TKR (NexGen LPS, Zimmer Inc., Warsaw, Indiana). According to the manufacturer, this implant is designed to avoid impingement of the anterior post in up to 14° of hyperextension without anteroposterior movement of the femoral component. The spine-cam mechanism is designed to work for knee flexion...
angles above 75°, providing stability in the sagittal plane and also allowing for posterior rollback in flexion to substitute for the posterior cruciate ligament.

The mean follow-up was for 19 months (4 to 49), the mean post-operative extension was -3° (-10° to 0°) and the mean post-operative flexion was 117° (55° to 135°). The mean knee score based on the Knee Society clinical rating system17 was 95 (82 to 100) and the functional score was 77 (35 to 100).

**Surgical technique.** All the operations were performed by the senior author (HM). The components were aligned to allow the mechanical axis to pass through the centre of the prosthetic knee. On the sagittal plane, the femoral bone cut was planned to be perpendicular to the anatomical axis and care was taken to avoid notching the anterior cortex. An 8 mm intramedullary femoral cutting guide was passed into the entry point on the femur, which was pre-determined by anteroposterior and lateral radiographs. The tibial bone cut on the sagittal plane was planned to be parallel to the lateral anatomical tibial slope. The rotational alignment was adjusted to the epicondylar axis and the tibial tuberosity. Soft tissue balancing was performed to achieve varus and valgus stability in both extension and flexion.

**Kinematic analysis.** Continuous sagittal radiological images of gait on a treadmill at 0.8 m/s were obtained for each patient using a flat-panel detector (Hitachi, Clavis, Tokyo, Japan). This produced 3 frames per second with an image area of 397 mm (H) × 298 mm (V), and 0.20 mm × 0.20 mm/pixel resolution (Fig. 1). The higher contrast resolution of the radiological images provided the basis for an even greater improvement in accuracy.18,19 The flat-panel detector was useful in capturing dynamic activities because of its broader outlook than fluoroscopy. Three images of single-leg stance and three of the swing phase were captured from different gait cycles and analysed using an image-matching technique.20 A total of 72 images were used for the analysis: 36 for each of the swing and stance phase.

The angles of flexion and axial rotation of the components were measured using the image-matching method.20 The positive or negative values of flexion were defined as flexion or extension of the femoral relative to the tibial component. The positive or negative values of rotation were defined as the internal or external rotation of the femoral relative to the tibial component. Impingement of the anterior post was determined by the intersection of the 3D computer-aided design (CAD) model surfaces of the femoral component and the tibial polyethylene insert. This was obtained by using the CAD program (SolidWorks 2001Plus SP3.0, SolidWorks Corporation, Concord, Massachusetts) (Fig. 2). The minimum distance between the femoral trochlea and the anterior aspect of the tibial post was also measured in the mid-sagittal plane of the tibial insert (Fig. 3). The positive or negative value of the minimum distance was defined as the anterior or posterior position of the femoral trochlea relative to the anterior aspect of the tibial post. The skeletal flexion angle between the axes of the femoral and tibial shafts was measured on the sagittal radiological images using an angle scale. A radiological assessment of the flexion angle of the femoral component and the posterior tibial tilt angle on the lateral view was performed according to the Knee Society roentgenographic evaluation.21 Post-operative limb alignment in the coronal plane was measured by drawing a mechanical axis on each limb on a full-
length standing radiograph. The weight-bearing ratio was calculated by measuring the distance from the medial edge of the proximal tibia to the point of intersection with the mechanical axis divided by the entire width of the proximal tibia.\textsuperscript{22,23} A percentage was calculated by multiplying this ratio by 100%. Statistical analysis was performed using a data analysis system (Stat View 5.0, Abacus Concepts Inc., Berkeley, California). The two-factor factorial analysis of variance (ANOVA) and post hoc tests (Bonferroni/Dunn) were used to determine the statistical significance at the 95% confidence interval level of the compared results (p < 0.05).
Results
The angles of skeletal flexion and of flexion of the components at the swing/stance phase are shown in Figure 4. At the stance phase, 12 of 36 images represented the flexed position (≤ 3.5°), and seven represented hyperextension of more than 15° (Fig. 5). The mean rotation angle at the swing/stance phase was -6.6° (SD 3.5)/-1.0° (SD 3.0). There was a significant difference in the angles of skeletal flexion (p < 0.0001), component flexion (p < 0.0001) and axial rotation (p < 0.0001) between the stance and swing phases.

Impingement of the anterior post was observed in all the 36 radiological images in 12 knees at the stance phase (Fig. 6). In at the swing phase, all images showed no contact in the anterior or posterior aspects of the tibial post. The mean amount of the minimum distance at the swing/stance phase was 13.4 mm (SD 6.0)/-0.9 mm (SD 0.8) and this was statistically significant (p < 0.0001).

The mean post-operative alignment of the femoral component on the lateral radiograph was 5.6° (SD 2.7) of flexion relative to the distal half of the axis of the femoral shaft. The mean post-operative alignment of the tibial component on the lateral radiograph was 5.9° (SD 2.9) of posterior tilt relative to the proximal half of the axis of the tibial shaft. The mean value of the sagittal alignment of the femoral and tibial components was 11.6° (SD 4.6). The mean post-operative weight-bearing ratio was 52% (SD 10).

Discussion
This study examined impingement of the anterior tibial post of a posteriorly-stabilised TKR during gait using a high-resolution flat-panel radiological detector. All the patients had a successful NexGen posteriorly-stabilised TKR and showed impingement of the anterior tibial post during the stance phase of gait. There was no hyperextension and/or instability on clinical examination in any of the knees. There was no evidence of component malpositioning on radiological analysis of the knees. In the stance phase, the mean skeletal alignment showed low flexion, but the average component alignment was approximately 6° of hyperextension. Even in low component flexion (≤ 3.5°), the intercondylar notch of the femoral component impinged on the anterior aspect of the tibial post. During gait, none of the knees flexed into the range of post-cam engagement > 75° flexion in NexGen LPS.

We have demonstrated in vivo 3D, impingement of the anterior post during gait in this study. Hyperextension of alignment of the component during the stance phase has been previously described using single-plane fluoroscopy. Banks et al. showed that 41% of knees demonstrated hyperextension during gait, and that the hyperextension of alignment of the component averaged 6°. They noted that the 5° anterior bow and the 5° posterior slope led to approximately 10° of relative hyperextension of the
component when the knee was in full extension. This is consistent with the findings in our study, which showed that the components were in an average of 12° of hyperextension relative to the sagittal mechanical axis of the knee, because the femoral components were in approximately 6° of flexion and the tibial components had approximately 6° of posterior slope.

Previous studies have indicated that the prevention of impingement of the anterior post depends on the technique of implantation. A flexed femoral component with an inclined tibial component can lead to impingement of the anterior portion of the femoral component on to the tibial post. Although the NexGen LPS was designed to allow for 14° of relative hyperextension of the component without impingement, we found that impingement occurs even without flexion of the femoral component and a posterior tibial slope. The posterior translation of the femur can lead to impingement without hyperextension. Previous studies of posterior cruciate-retaining TKRs using dynamic fluoroscopic analysis revealed that the absence of the ACL caused posterior femoral contact during extension. During gait, the anteriorly directed shear force on the tibia is normally resisted by the ACL. In the posteriorly stabilised TKR, engagement of the anterior portion of the femoral component on to the tibial post provides a functional substitute for the ACL, resulting in limitation of posterior displacement of the femur relative to the tibia. Stiehl et al observed that patients having a posterior cruciate-retaining TKR experienced posterior contact positions of both condyles, compared with patients having an anterior and posterior cruciate-retaining TKR. Komistek et al noted that anterior contact in an anterior cruciate-retaining TKR can be attributed to the presence of the ACL, which resists the anterior tibial shear forces during gait.

In the NexGen LPS, the relatively flat shape of the anterior aspect of the post caused impingement to be located on the medial and lateral anterior corners of the tibial post. In the NexGen LPS, the relatively flat shape of the anterior aspect of the post caused impingement to be located on the medial and lateral anterior corners of the tibial post. This can lead to excessive stress and wear because of edge loading. This phenomenon has also been seen in previous retrieval studies. Mikulak et al observed that all the 12 retrieved components in their study had evidence of damage to the anterolateral and anteromedial aspects of the post. Haas has also noted impingement at the corners of the tibial post in the NexGen LPS. The configuration of the intercondylar notch of the femoral component and the anterior aspect of the tibial post should be designed to provide a larger contact area and prevent edge loading. This may cause chronic wear and fracture of the polyethylene post. Recent modifications to provide a larger area of contact have mainly focused on the post-cam mechanism. Li et al demonstrated that the contact forces in the tibial post increased dramatically as the knee hyperextended, and that the contact force was minimal at 30° of flexion. Surgeons should therefore avoid excessive flexion of the femoral component and posterior slope of the proximal tibial resection.

There are some limitations to this study. Firstly, it did not provide full kinematic analysis of the entire range of move-
ment. It was therefore not possible to observe in which degrees of flexion the intercondylar notch of the femoral component impinged on the anterior aspect of the tibial post. Secondly, the study was limited by the small number of patients. As a result, we could not conclusively state that the cam-post in the NexGen LP always engaged anteriorly during gait. However, the study did reveal that anterior impingement of the tibial post was a repeatable phenomenon. Finally, the results presented here were obtained using a single type of implant. Further investigations with comparisons of different designs are required.

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References
