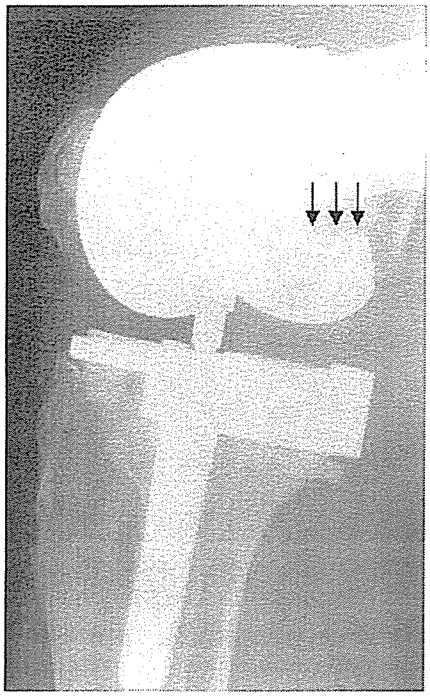

Fig. 3-B

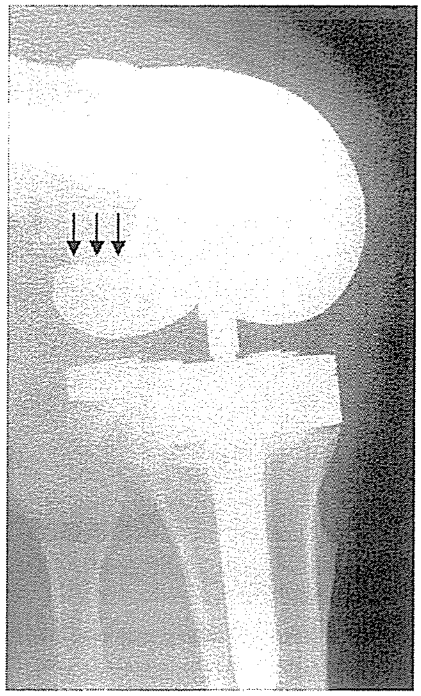

Fig. 3-C

Figs. 3-B and 3-C Oblique posterior condylar radiographs of the same knee as shown in Fig. 3-A. The posterior aspects of the femoral condyles are visible on these radiographs (arrows).

termination of the side of the abnormality is difficult. Conventional or computed tomography is not useful for assessing the posterior aspects of the femoral condyles because the metal prosthesis produces considerable artifact. Puri et al.[5] recommended the use of helical computed tomography with metal-artifact minimization for the detection of acetabular osteolysis after total hip arthroplasty. However, we do not believe that this method can adequately evaluate the bone-implant interface in an area surrounded by a metal implant, such as the posterior aspects of the femoral condyles after total knee arthroplasty.

Radiographic analysis with use of the oblique posterior condylar view is technically easy, can be performed in the office with a regular x-ray machine, and allows the lateral and medial posterior femoral condyles to be assessed separately. This technique is reproducible and is significantly more accurate than standard radiographs for the detection of radiolucencies of the posterior aspects of the femoral condyles. Even in a knee with a posterior stabilized replacement, it is possible to observe the posterior aspects of the condyles despite the presence of the cam mechanism. ■

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Anteroposterior Stability in Posterior Cruciate Ligament–Retaining Total Knee Arthroplasty

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Abstract: Anteroposterior stability was evaluated using a KT-2000 arthrometer in 18 patients (21 knees) continuously for up to 5 years after posterior cruciate ligament–retaining total knee arthroplasty. The Knee Society score, functional score, and the maximum flexion angle did not change significantly during the postoperative period. The mean anteroposterior displacement of all joints studied at both 30° and 75° of flexion did not change significantly during the 5-year period of observation, but 4 individual knees did exhibit increases in anteroposterior displacement of 3 mm or more. One of the 4 knees exhibited osteolysis beneath the tibial component. Three of these knees had undergone high tibial osteotomy at some time before the total knee arthroplasty. **Key words:** anteroposterior stability, posterior cruciate ligament, total knee arthroplasty.

Controversy still exists as to the relative merits of retaining or substituting the posterior cruciate ligament in total knee arthroplasty. This ligament is expected to play an important role in maintaining anteroposterior stability after total knee arthroplasty, and, when retained, it is thought to stabilize the knee by preventing posterior translation, increase the range of motion, and improve stair-climbing ability [1-3]. Because of its implications in postoperative knee function, wear of ultra–high-molecular-weight polyethylene, and prosthesis stability, anteroposterior displacement is one of the most important indices in assessing the success of a total knee arthroplasty [1-8].

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Anteroposterior stability after posterior cruciate ligament–retaining total knee arthroplasty has been studied by various methods [2,3,5,7-15]. In a clinical study, it was reported that approximately half of all knees that had undergone posterior cruciate ligament–retaining total knee arthroplasty did not have good anteroposterior stability in flexion when examined an average of 9 years after surgery [2]. In that study, however, it was not clear when the anteroposterior instability developed, whether it was present immediately after surgery or progressively worsened during the postoperative period.

The purpose of this study was to evaluate anteroposterior stability continuously for up to 5 years after posterior cruciate ligament–retaining total knee arthroplasty. Clinical factors related to changes in anteroposterior stability were also evaluated.

Materials and Methods

Between August 1997 and April 1999, total knee arthroplasty was performed on 71 knees in 58 patients at the authors' hospital. The posterior cruciate ligament was retained when it was intact in tension and appearance at the time of surgery; such posterior cruciate ligament–retaining total knee arthroplasty procedures were performed on 43 knees in 36 patients. Of these, 21 knees in 18 patients, who agreed to be tested, were available for study. Patients in the study group were evaluated before surgery (21 knees), at 1 month (17 knees), at 3 years (16 knees), and at 5 years (21 knees) after surgery. The mean follow-up period for all the patients was 63 months (range, 49-72 months). The study group consisted of 3 men and 15 women. Sixteen patients had osteoarthritis, one patient had rheumatoid arthritis, and one patient had spontaneous osteonecrosis of the femoral condyle. The mean patient age at the time of operation was 69.8 years (range, 56-82 years). The personal data for all patients are presented in Table 1.

Posterior cruciate ligament–retaining total knee arthroplasty was performed using the Performance Modular Total Knee System (Biomet, Warsaw, Ind) according to the instructions provided by the manufacturer. The distal femoral cutting block was aligned using an intramedullary guide, and the proximal tibial cutting block was aligned using an extramedullary guide. In all cases, there was no severe bone deficiency that needed bone graft and augmentation. In all cases, the posterior cruciate

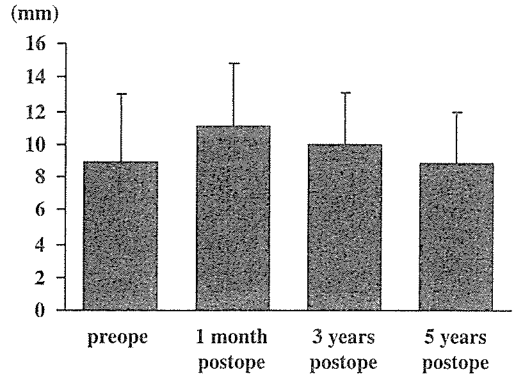

Fig. 1. The mean anteroposterior displacement measurements at 30° of flexion.

ligament was intact in tension and appearance at the time of surgery and was thus retained. Soft tissue was balanced so as to achieve varus and valgus stability. The tension of the posterior cruciate ligament was assessed in the manner described by Swany and Scott [16]: it was judged to be tight when there was liftoff of the anterior portion of the tibial component at 90° of flexion, when the femoral component was articulated in the posterior third of the polyethylene insert, and when the entire ligament itself was very firm by palpation at 90° of flexion. When excessive tension was observed, the posterior cruciate ligament was

Table 1. The Personal Data for all Patients (21 Knees in 18 Patients)

Patient	Age/sex	Site	Diagnosis	Previous Surgery	Ligament Release				Cement (Femur/Tibia)
					PCL	Medial	Lateral	Posterior	
1	65/M	R	OA	HTO	+	–	–	+	–/+
2	82/F	R	OA	–	–	–	–	–	+/+
3	66/M	L	Necrosis	–	–	+	–	–	–/+
4	64/F	R	RA	–	–	–	–	–	–/+
5	79/F	L	OA	–	–	–	–	–	–/+
6	72/F	L	OA	–	–	+	–	–	–/+
7	60/F	R	OA	–	–	–	–	–	–/+
		L	OA	–	–	–	–	–	–/+
8	72/F	R	OA	–	–	+	+	–	–/+
9	67/F	L	OA	–	–	+	–	+	–/+
10	74/F	R	OA	–	–	–	–	–	–/+
		L	OA	–	+	+	–	–	–/+
11	73/F	R	OA	–	–	–	–	–	–/+
12	77/F	L	OA	–	+	+	–	–	–/+
13	56/F	R	OA	HTO	–	–	+	–	–/+
14	63/F	R	OA	HTO	+	–	–	–	–/+
15	69/F	R	OA	–	–	+	–	–	–/+
16	78/F	R	OA	–	–	–	–	–	–/+
17	67/F	L	OA	–	+	+	–	–	–/+
18	74/M	R	OA	–	+	+	–	–	–/+
		L	OA	–	+	–	–	+	–/+

Patients 16, 17, and 18 were not measured at 1 month and 3 years postoperatively by KT-2000 arthrometer. M indicates male; F, female; R, right; L, left; PCL, posterior cruciate ligament; OA, osteoarthritis; RA, rheumatoid arthritis; Necrosis, spontaneous osteonecrosis of the femoral condyle; HTO, high tibial osteotomy.

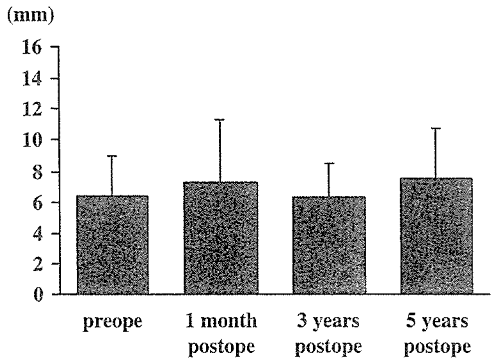

Fig. 2. The mean anteroposterior displacement measurements at 75° of flexion.

released in the following manner. The posterotibial spine was trimmed, and the posterior cruciate ligament was released subperiosteally in increments of 1 to 2 mm with retesting. The posterior cruciate ligament was released for 7 knees in 6 patients (Table 1). A curved tibial insert was used for all knees. Twenty knees had their femoral components fixed without cement and had the tibial components cemented, and one knee had both the femoral and tibial components cemented.

Anteroposterior displacement of the knee was measured preoperatively and at 1 month, 3 years, and average of 5 years after surgery using a KT-2000 arthrometer (Medmetric, San Diego, Calif). The relative movement between the patellar and tibial tubercle sensor pads was recorded at both 30° and 75° of flexion when an anterior force of 133 N and a posterior force of 89 N were applied to the lower leg. During these tests, all subjects were instructed and observed to keep their quadriceps relaxed. Because the resting position of the femoral component in relation to that of the tibial component was variable, total displacement was measured [2,14]. Measurements were done 3 times, and the average value of the 3 measurements was used for evaluation. The Knee Society score was used to evaluate knee status preoperatively and at 3 years and an average of 5 years postoperatively. Radiological assessment of the femorotibial angle (preoperatively), posterior tibial tilting angle that means inclination between tibial shaft axis and the tibial plateau at the lateral view (preoperatively, 5 years after surgery), and the presence of radiolucent lines (5 years after surgery) was performed according to the Knee Society roentgenographic evaluation and scoring system [17]. Differences in anteroposterior displacement and knee status were evaluated at each preoperative and postoperative period of observation. In relation to release of posterior cruciate ligament, differences of anteroposterior displacement between two groups (release groups and nonrelease groups) were evaluated.

As to the change in anteroposterior displacement during the postoperative period, an "AP-lax knee" was defined as a knee whose anteroposterior displacement increased by more than 3 mm at 75° of flexion; a knee with less than 3 mm increase in anteroposterior displacement was defined as an "AP-stable knee." This threshold was chosen because 2 mm represented the maximum margin of error of the KT-2000 arthrometer [18-20]. The Knee Society score and radiographic findings of AP-lax and AP-stable knees were compared 5 years after surgery. In addition, preoperative knee condition (history of previous surgery on the same side as the total knee arthroplasty, the Knee Society score, femorotibial angle, and posterior tibial tilting angle) and operative findings (successful balancing of soft tissue and release of the posterior cruciate ligament) were also compared between the two groups. Mann-Whitney *U* test and Fisher exact probability test were used to determine the statistical significance at the 95% confidence level of compared results.

Results

The mean anteroposterior displacement measurements at 30° of flexion were 9.0 ± 4.0 mm (range, 3.2-20.0 mm) preoperatively and 11.1 ± 3.7 mm (range, 5.0-19.0 mm) at 1 month, 10.0 ±

Table 2. Knee Society Score and Functional Score Before and After Surgery

Period	Knee Society Score	Maximum Flexion Angle (°)	Total Functional Score	Walking	Stairs
Preoperation	59.4 ± 12.4	120.5 ± 17.3	34.5 ± 19.9	17.6 ± 10.9	21.4 ± 13.1
3 y after surgery	92.3 ± 4.8*	108.8 ± 14.1*	76.9 ± 16.4*	43.1 ± 7.9*	36.2 ± 12.0*
5 y after surgery	90.3 ± 4.6*	105.7 ± 13.0*	64.5 ± 22.1*	36.7 ± 11.5*	31.7 ± 12.8*

Values are expressed as mean ± SD.
*Significantly different from preoperation ($P < .05$).

3.1 mm (range, 5.1-15.0 mm) at 3 years, and 8.9 ± 3.1 mm (range, 4.4-15.5 mm) at 5 years after surgery (Fig. 1). The mean anteroposterior displacement at 30° of flexion did not change significantly within 5 years after surgery after posterior cruciate ligament–retaining total knee arthroplasty (1 month to 3 years: P = .51; 1 month to 5 years: P = .07; 3-5 years: P = .23).

The mean anteroposterior displacement measurements at 75° of flexion were 6.4 ± 2.6 mm (range, 2.2-13.8 mm) preoperatively and 7.3 ± 4.0 mm (range, 2.6-20.0 mm) at 1 month, 6.3 ± 2.2 mm (range, 3.4-10.8 mm) at 3 years, and 7.5 ± 3.2 mm (range, 2.3-15.5 mm) at 5 years after surgery (Fig. 2). The mean anteroposterior displacement at 75° of flexion did not change significantly within 5 years after surgery (1 month to 3 years: P = .56; 1 month to 5 years: P = .25; 3-5 years: P = .07).

Knee Society score, functional score, and the maximum flexion angle are shown in Table 2. Statistically significant differences were detected between the preoperative and postoperative periods, but there was no significant difference in these values between 3 and 5 years after surgery.

In relation to release of posterior cruciate ligament, posterior cruciate ligament was released in 7 knees (release group) and not released in 14 knees (nonrelease group). The mean anteroposterior displacement measurements at 30° of flexion was 8.7 ± 1.7 mm (range, 7.2-12.3 mm) in release group and 9.0 ± 3.7 mm (range, 4.4-15.5 mm) in nonrelease group at 5 years after surgery. There was no significant difference in knee laxity between the two groups (P = .88). The mean anteroposterior displacement measurements at 75° of flexion was 6.5 ± 3.9 mm (range, 3.0-12.3 mm) in release group and 8.0 ± 2.8 mm (range, 2.3-15.3 mm) in nonrelease group at 5 years after surgery. There was no significant difference in knee laxity between the two groups (P = .50).

There were 4 knees (patients 1, 2, 13, and 14) whose anteroposterior displacement at 75° of flexion increased by more than 3 mm during the postoperative period (AP-lax knees); the other 13 knees observed did not exhibit increases in anteroposterior displacement of more than 3 mm (AP-stable knees). Four knees (patient 16, 17, and 18) were excluded in this comparison because their anteroposterior displacements at 1 month and 3 years after surgery were not measured by the KT-2000 arthrometer. The changes in anteroposterior displacement at 75° of flexion were as follows: patient 1, from 4.3 to 8.8 mm (4.5 mm); patient 2, from 5.7 to 8.7 mm (3.0 mm); patient 13, from 4.4 to 15.3 mm (10.9 mm); and patient 14, from 7.0 to 12.3 mm (5.3 mm). The mean change in anteroposterior displacement at 75° of flexion during the postoperative period was 5.9 ± 3.5 mm (range, 3.0-10.9 mm) in AP-lax knees and −0.7 ± 4.8 mm (range, −15.4 to 2.8 mm) in AP-stable knees (P = .003). A comparison of knee function between AP-lax and AP-stable knees at 5 years after surgery is shown in Table 3. No

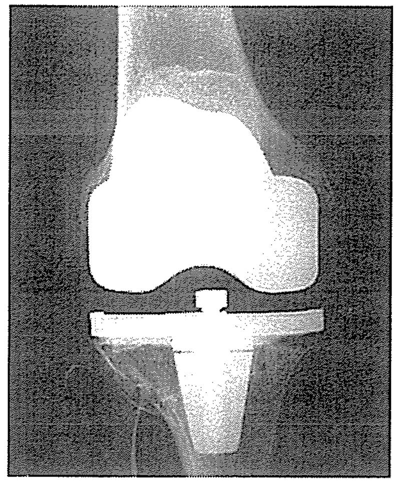

Fig. 3. Radiological assessment at 5 years after surgery; 3-mm-deep (zone 1) osteolysis beneath the tibial component was found in one (patient 13) of the AP-lax knees according to the Knee Society roentgenographic evaluation and scoring system.

Table 3. Knee Society Score and Radiographic Findings of AP-Lax and AP-Stable Knees at 5 Years After Surgery

Knee Condition	Knee Society Score	Maximum Flexion Angle (°)	Total Function Score	Walking	Stairs	Posterior Tibial Tilting Angle (°)
AP-lax knees	89.8 ± 2.9 (86-92)	107.5 ± 13.2 (90-120)	58.8 ± 29.3 (25-90)	37.5 ± 15.0 (20-50)	25.0 ± 17.3 (0-40)	5.0 ± 1.4 (4-7)
AP-stable knees	89.5 ± 5.2 (80-100)	107.3 ± 14.7 (90-130)	69.6 ± 17.5 (40-90)	36.2 ± 12.6 (40-90)	35.8 ± 8.6 (15-50)	3.8 ± 2.5 (1-8)

Values are expressed as mean ± SD.

Table 4. Knee Society Score and Radiographic Findings of AP-Lax and AP-Stable Knees Before Surgery

Knee Condition	Knee Society Score	Maximum Flexion Angle (°)	Femorotibial Angle (°)	Posterior Tibial Tilting Angle (°)
AP-lax knees	65.5 ± 6.6 (57-73)	116.3 ± 22.9 (90-145)	175.8 ± 6.3 (171-185)	9.5 ± 4.7 (3-14)
AP-stable knees	58.1 ± 14.5 (23-75)	122.7 ± 17.2 (90-140)	181.7 ± 7.4 (167-191)	10.7 ± 3.5 (5-16)

Values are expressed as mean ± SD.

statistically significant differences in any measured functional parameters were observed between the two groups (Knee Society score: P = .81; maximum flexion angle: P = .95; total functional score: P = .53; walking: P = .75; stairs: P = .16; posterior tibial tilting angle: P = .33). The stairs score of 0 for one patient (patient 2) was not due to knee pain or instability, but to a decrease of general activity. There was no severe polyethylene wear in the two groups; however, one case of 3-mm-deep (zone 1) osteolysis beneath the tibial component was found in one of the AP-lax knees (patient 13) (Fig. 3). There were no complaints of knee pain, instability, swelling, or giving way at 5 years after surgery in either of the two groups. A comparison of preoperative knee condition between the two groups is shown in Table 4. There were no significant differences between the two groups regarding the Knee Society score or radiographic measurements (Knee Society score: P = .46; maximum flexion angle: P = .57; femorotibial angle: P = .19; posterior tibial tilting angle: P = .61), but 3 of the 4 patients with AP-lax knees had a history of high tibial osteotomy performed before the total knee arthroplasty. In all 3 knees, the increase in anteroposterior displacement at 75° of flexion after 5 years was more than 4 mm (4.5, 10.9, and 5.3 mm). Among the patients with AP-stable knees, none had had prior knee surgery. The difference in history of high tibial osteotomy between the two groups was highly statistically significant (P = .006). Finally, the intraoperative findings from the total knee arthroplasties for the two groups are shown in Table 5. There was no significant difference in these parameters between the two groups (release of posterior cruciate ligament: P = .22; release of medial: P = .10; release of lateral: P = .43; release of posterior: P = .43).

Table 5. The Intraoperative Findings Between the AP-Lax and AP-Stable Knees

Operative Findings	AP-lax Knees (4 Knees)	AP-stable Knees (13 Knees)
Release of PCL	2/4 (50)	2/13 (15)
Release of medial	0/4 (0)	7/13 (54)
Release of lateral	1/4 (25)	1/13 (8)
Release of posterior	1/4 (25)	1/13 (8)

Values are expressed as number (%).

Discussion

During total knee arthroplasty, the posterior cruciate ligament is retained due to its crucial role in postoperative stability, not only in preventing posterior subluxation but also in dissipating shear and tensile stress on polyethylene joint components and bone-implant interfaces [1-3]. There have been some reports that posterior-stabilized total knee arthroplasty results in significantly greater anteroposterior stability than does posterior cruciate ligament–retaining total knee arthroplasty [4,10,11]. However, anteroposterior constraint by the post-cam mechanism may cause high shear forces to be transmitted through the bone to the implant interface, leading to aseptic loosening [13,15,21,22]. In addition to this, posterior-stabilized total knee arthroplasty requires bone resection from the intercondylar region of the femur to accommodate the post-cam mechanism. Mechanical failure due to fracture of the polyethylene tibial post has been reported recently [21-23]. We believe that the posterior cruciate ligament should be retained as often as possible to maintain its effective physiological utility after total knee arthroplasty.

In a clinical study using the KT-2000 arthrometer, it was reported that approximately half of all knees that had undergone posterior cruciate ligament–retaining total knee arthroplasty did not have good anteroposterior stability in flexion at an average of 9 years after surgery [2]. In the present study, the mean anteroposterior displacement at both 30° and 75° of flexion did not change within 5 years after posterior cruciate ligament–retaining total knee arthroplasty. There were no significant changes throughout the postoperative period in the Knee Society score, functional score, or maximum flexion angle. On average, anteroposterior stability and knee function are thus preserved for up to 5 years after this procedure as well as the result at 3 years after surgery [14]. In the present study, statistical comparison was not made between the preoperative and postoperative laxity. Preoperative knee laxity was shown as the basic data because laxity of knees is different individually. However, preoperative laxity was not used as a reference point to show changes of laxity in the postoperative period because there are many variables in surgery.

When each knee was considered individually, however, we noticed that anteroposterior stability was impaired in 4 knees. Among the 17 knees examined, 4 were AP-lax knees. One case of osteolysis beneath the tibial component was found in the knee of patient 13, for which the anteroposterior displacement increased by 10.9 mm; however, even at 5 years after surgery, neither this patient nor any of the others in both groups complained of knee pain, instability, swelling, or giving way. No significant differences were observed in preoperative knee scores or radiograph and intraoperative findings of AP-lax and AP-stable knees.

Patients with 3 of the 4 AP-lax knees had a history of high tibial osteotomy before their total knee arthroplasty. Many studies have reported inferior clinical results of total knee arthroplasty after high tibial osteotomy compared with primary total knee arthroplasty [24-28]; however, few studies have specifically evaluated knee stability in patients receiving total knee arthroplasty after high tibial osteotomy. Although it is difficult to say conclusively that a history of high tibial osteotomy jeopardizes the anteroposterior knee stability after posterior cruciate ligament–retaining total knee arthroplasty from this small number of patients, the findings of the present study agree with previous results obtained by Walther et al [27]. They reported that Knee Society scores were significantly lower in arthroplasty after high tibial osteotomy than in arthroplasty without previous knee surgery, primarily because of decreased anteroposterior stability and pain. Although knee stability was assessed simply by manual testing by an examiner, these authors concluded that inadequate posterior cruciate ligament function may occur more often after arthroplasty conducted on a background of prior high tibial osteotomy. In the current study, we evaluated knee stability objectively using a KT-2000 arthrometer, and all 3 knees that had been subjected to high tibial osteotomy exhibited an increase in anteroposterior instability.

The underlying cause of the development of anteroposterior instability in the knee after high tibial osteotomy is unclear. Anteroposterior instability in this study does not directly mean posterior cruciate ligament insufficiency, but increment in anteroposterior laxity at 75° of flexion may reflect changes in the tension in the posterior cruciate ligament because posterior cruciate ligament is a primary restraint for anteroposterior instability in knee flexion. In osteoarthritic knees, the posterior cruciate ligament has been reported to demonstrate histological degenerative changes [29]. Degenerative changes might be accelerated in knees subjected to high tibial osteotomy, although the tension and appearance of the posterior cruciate ligament at the time of surgery seemed normal. Several authors have reported that soft tissue balancing is more difficult in total knee arthroplasty after high tibial osteotomy [24-28,30]. Release of the posterior cruciate ligament was performed in 2 of the 3 affected knees in this study, which may be due to a decrease in the posterior tibial slope or to an overly tight posterior cruciate ligament. Release of posterior cruciate ligament would result in additional increases in anteroposterior instability to some extent [9,15]. Hofmann and Kane [30] reported that it is common to find the posterior cruciate ligament shortened and scarred in total knee arthroplasty after high tibial osteotomy and that adequate balancing of the knee would require posterior cruciate ligament resection and using subsequent prosthetic replacement. Despite the small number of patients observed, this study corroborates these previous findings and suggests that posterior-stabilized total knee arthroplasty may be preferable for knees that have undergone a prior high tibial osteotomy.

The current study has some limitations. Our evaluation using the KT-2000 arthrometer was static and was the only anteroposterior stability test that we used. Rollback of the femoral component, which is another important role of the posterior cruciate ligament, was not evaluated. Motion of the knee joint under weight-bearing conditions should be analyzed and compared with measurements of anteroposterior stability after posterior-stabilized total knee arthroplasty.

In summary, this study quantitively evaluated anteroposterior stability both preoperatively and for an average of 5 years after posterior cruciate ligament–retaining total knee arthroplasty. On average, anteroposterior stability remained constant, and there were no complaints of knee pain, instability, swelling, or giving way for up to 5 years after surgery. However, 4 knees exhibited an increase in anteroposterior displacement of more than 3 mm; in one of these, osteolysis beneath the tibial component was found. Most significantly, 3 of these 4 cases had had a history of high tibial osteotomy before the total knee arthroplasty.

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Validity of an oblique posterior condylar radiographic view for revision total knee arthroplasty

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We have previously developed a radiographic technique, the oblique posterior condylar view, for assessment of the posterior aspect of the femoral condyles after total knee arthroplasty. The purpose of this study was to confirm the validity of this radiographic view based upon intra-operative findings at revision total knee arthroplasty. Lateral and oblique posterior condylar views were performed for 11 knees prior to revision total knee arthroplasty, and radiolucent lines or osteolysis of the posterior aspect of the femoral condyles were identified. These findings were compared with the intra-operative appearance of the posterior aspects of the femoral condyles. Statistical analysis showed that sensitivity and efficacy were significantly better for the oblique posterior condylar than the lateral view. This method can, therefore, be considered as suitable for routine follow-up radiographs of the femoral component and in the pre-operative planning of revision surgery.

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Osteolysis is a well-described complication of total hip arthroplasty and is increasingly recognised after total knee arthroplasty (TKA).[1,2] Fehring et al[3] showed early failure of TKA because of osteolysis. Although, osteolysis commonly occurs in the posterior part of the femoral condyles,[4] this is an area which is often difficult to evaluate on a true-lateral radiograph; an abnormality in one condyle may be obscured by the other. Moreover, even if an abnormality is detected, it can be difficult to determine which condyle is affected. We have performed several revision procedures in which the lateral radiograph appeared normal pre-operatively, but in which an augmentation block was necessary because of massive bone resorption of the posterior aspect of a femoral condyle.

We developed an oblique posterior condylar radiographic view for evaluation of the posterior femoral condyles after TKA. With this view, the medial and lateral condyles can be observed separately. We have already reported the efficacy and reproducibility of this view in detecting abnormalities of the posterior aspect of the femoral condyles.[5] However, it is still unclear whether these radiographic changes reflect true local bony abnormalities.

The purpose of this study, therefore, was to confirm the validity of the oblique posterior condylar view based on intra-operative findings at revision TKA. We focused specifically on the detection of bony deficiency in the posterior condyles rather than the detection of radiolucent lines.

Patients and Methods

We selected 11 consecutive revision TKAs (ten patients) which had been performed at our hospitals between 2001 and 2004. There were two men and eight women with a mean age of 78.6 years (60 to 88) at the time of revision surgery. The mean interval between the primary and revision procedures was 112.5 months (63 to 198). Lateral and oblique posterior condylar views were obtained pre-operatively for all patients, with any osteolytic or bony defects of the posterior aspect of the femoral condyles being regarded as abnormal. The oblique posterior condylar view was obtained with the patient sitting with the knee flexed to 90°. The x-ray beam was directed horizontally, and bilateral oblique views of the knee (45° to 50°) were obtained. The radiographic findings for both the lateral and oblique posterior condylar views were then related to the state of the posterior aspect of the femoral condyles during revision TKA after removal of the femoral component. As the lateral radiographic view does not permit an assessment of the medial and lateral condyles separately, only one judgment for each knee was possible. In contrast, the oblique posterior condylar view allowed an assessment of both condyles, so

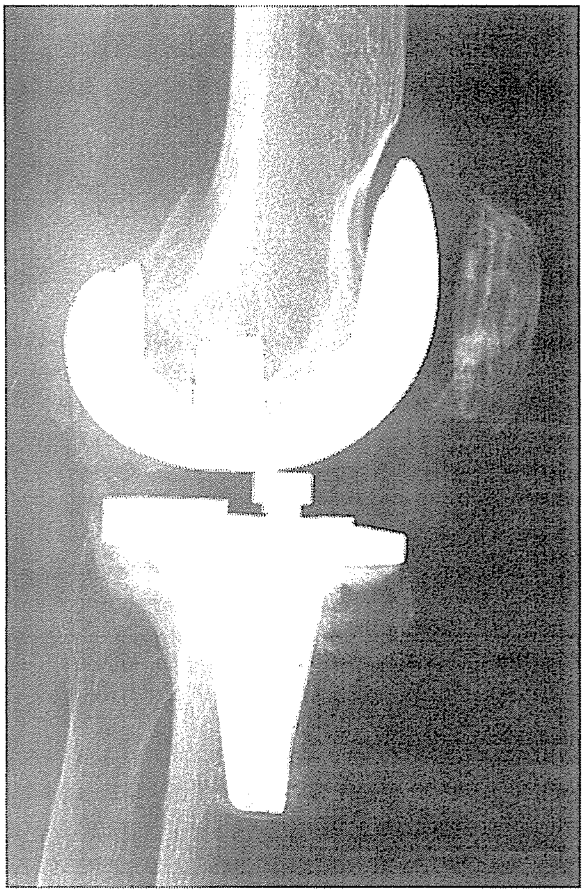


Fig. 1

Lateral radiograph showing the posterior aspect of the femoral condyle which appears normal.

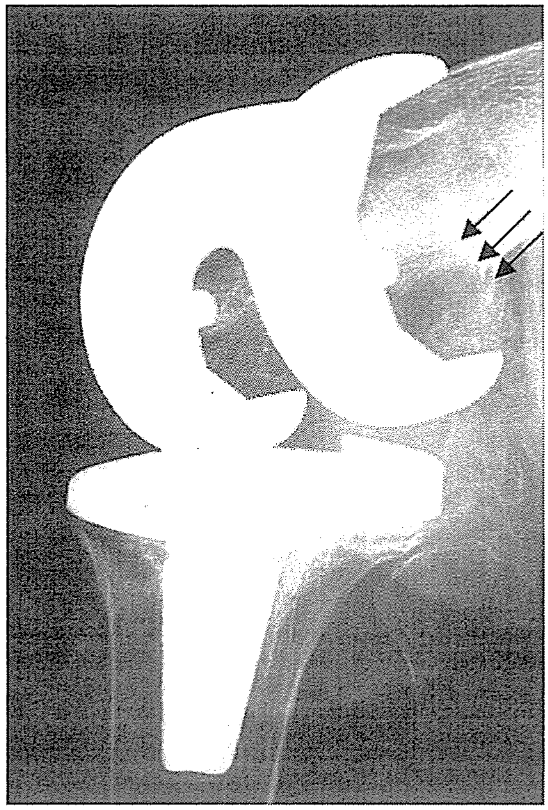


Fig. 2a

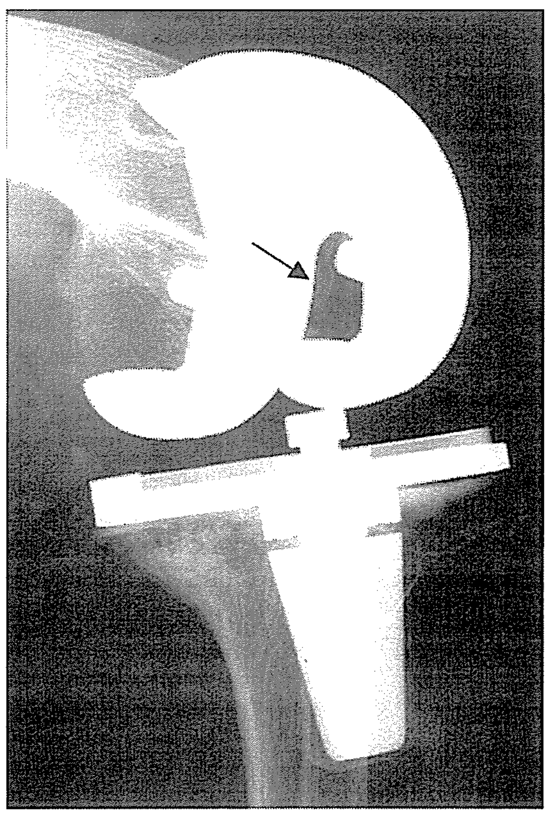


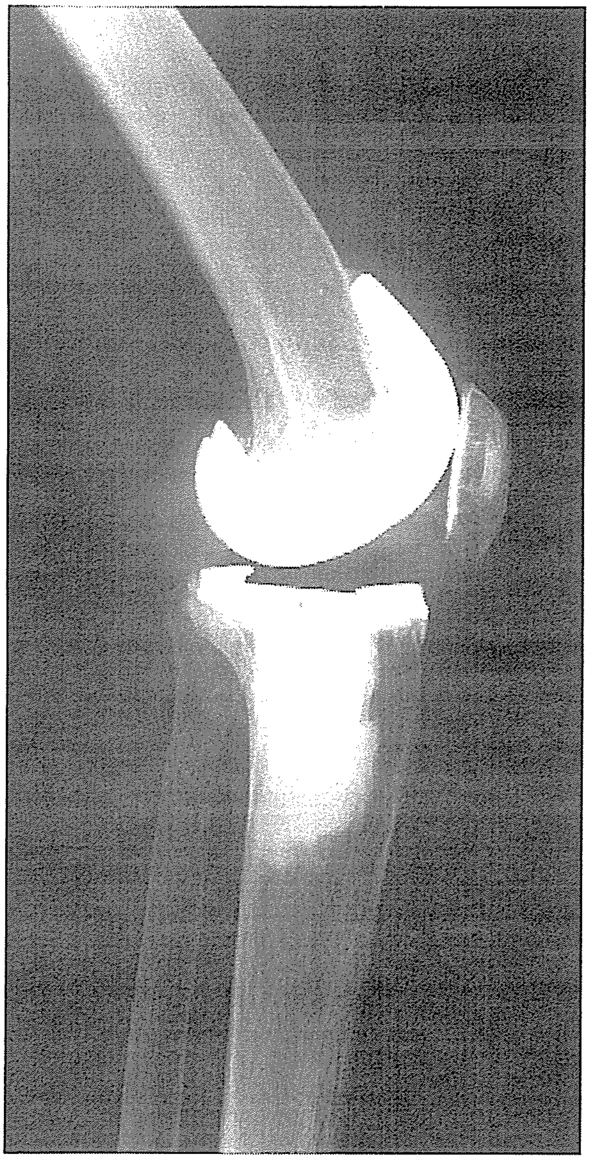
Fig. 2b

Figures 2a and b – The oblique posterior condylar radiographic views of the same knee as in Figure 1.

two judgments for each knee were possible. In order to validate the lateral view, the intra-operative findings were considered normal only if both condyles were normal. In the oblique posterior condylar view, the radiographic findings for both the medial and lateral condyles were compared with the intra-operative situation. Sensitivity, specificity, and efficacy were calculated for both the lateral and oblique posterior condylar views. Statistical analysis was performed using Fisher's exact probability test with values for $p < 0.01$ being regarded as significant.

Results

On the lateral view, ten of the 11 knees were regarded as normal with only one condyle being judged abnormal; this showed massive osteolysis intra-operatively. However, eight knees showed bony defects in the femoral condyle intra-operatively. On the oblique posterior condylar view, 22 radiographs were evaluated. From these, 11 condyles were regarded as abnormal, all of which showed bony defects in a femoral condyle intra-operatively. Typically, no abnormalities were seen in the posterior aspect of the femoral condyles on the lateral view (Fig. 1). However, the



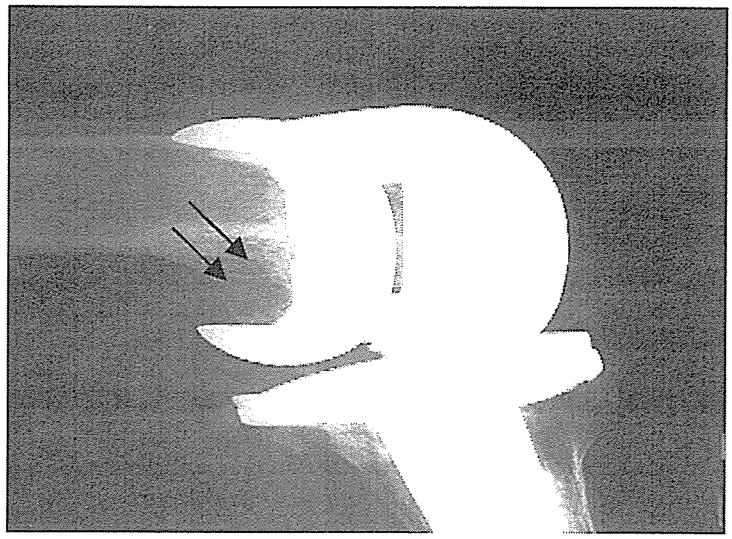


Fig. 3b

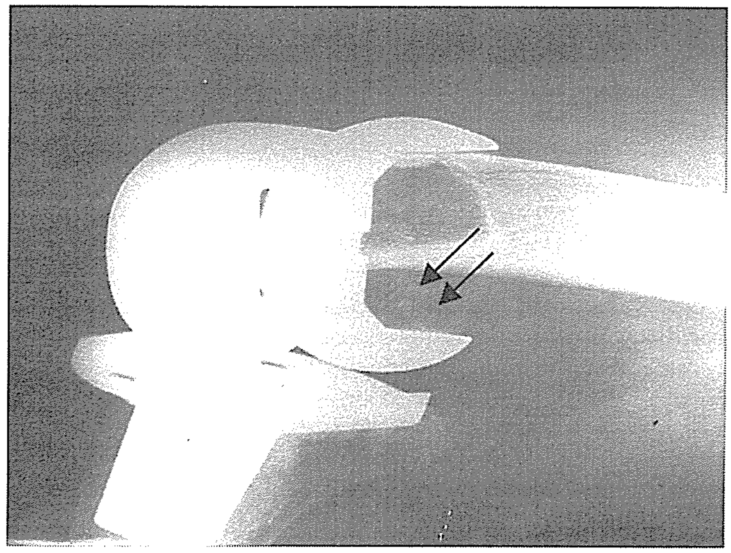


Fig. 3a

Fig. 3c

Radiographs of a posterior-stabilised total knee arthroplasty which show good views of the posterior femoral condyles a) lateral and b, c) oblique posterior condylar.

oblique posterior condylar view clearly showed osteolysis of the lateral femoral condyle (Fig. 2) which was confirmed intra-operatively. We assessed 11 knees as normal on the oblique posterior condylar view. Two of these, however, had bony defects intra-operatively. In one the radiographic assessment of the posterior femoral condyle was difficult because of severe metallosis.

The sensitivity of the lateral and oblique posterior condylar radiographic views was 0.111 and 0.846, respectively, while specificity was 1.00 for both and efficacy was 0.273 and 0.909, respectively. Statistical analysis showed that sensitivity and efficacy were significantly better for the oblique posterior condylar than the lateral radiographic view ($p < 0.002$ and $p < 0.005$, respectively).

Discussion

Rodriguez et al[6] reported that the majority of osteolytic lesions seen in a posterior-stabilised TKA are on the femoral side. Huang et al[4] also described osteolysis in the distal femur, most commonly in the posterior part of the femoral condyles. However, the lateral radiographic view cannot reliably demonstrate radiolucency of the posterior femoral condyles after TKA. Rotation of the X-ray beam by a few degrees does not necessarily reveal a radiolucency adjacent to the component.[7-9] Even with a true lateral radiograph, abnormal findings in one condyle may be obscured by the other. Furthermore, determination of the side of the abnormality is difficult. Particularly in a posterior-stabilised TKA, visualisation of the posterior aspects of the femoral condyles may be blocked by the cam mechanism of the femoral component.

Consequently, routine radiographs usually underestimate the presence and extent of osteolysis found at revision surgery and this has been highlighted by Van Loon et al.[10] Nadaud, Fehring and Fehring[11] recommended oblique radiographs in order to identify femoral osteolysis around a posterior-stabilised implant. Their method may be useful for massive osteolysis, but cannot show the interface between the posterior flange and the posterior part of the femoral condyle.

In contrast, the oblique posterior condylar view is technically easy, and allows the lateral and medial femoral condyles to be assessed separately. It is reproducible and significantly more accurate than the lateral radiographic view.[5] Intra- and inter-observer agreement for the oblique posterior condylar view was excellent (kappa mean of intra-observer agreement 0.888 (0.82 to 1.00); kappa mean of inter-observer agreement 0.793 (0.74 to 0.82)).[5] Even in posterior-stabilised knees, it is possible to see the posterior femoral condyles (Fig. 3) and we found intra- and inter-observer agreement to be excellent. For revision TKA, in particular we have found the oblique posterior condylar radiographic view to be useful for judging the need for augmentation or bone graft.

There are some drawbacks to the oblique posterior condylar view. First, it has a blind spot at the interface between the posterior aspect of the femoral condyles and the posterior flange. Secondly, it cannot be performed in patients with severe limitation of flexion angle of the knee, because the tibial component would block the femoral condyle. Thirdly, in patients with severe metallosis, assessment of the posterior aspect of the femoral condyles may be difficult.

Despite these problems, the oblique posterior condylar radiographic view is an easy and accurate procedure for evaluating radiolucencies of the posterior femoral condyles after TKA. It may be considered as suitable for routine follow-up radiographs of the femoral component and in preoperative planning for revision surgery.

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高機能次世代人工膝関節の開発

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はじめに

人工膝関節（以下 TKA）は，高度に障害された関節表面を合金と超高分子量ポリエチレンからなるインプラントで置き換えることによって，疼痛を軽減し関節機能の回復をはかる術式である．近年，飛躍的に手術症例数は増加しており，国内での人工膝関節の件数はすでに年間4万例を越えている．適応疾患は変形性膝関節症や関節リウマチなどであり，高度の関節破壊に伴う強い疼痛や可動域制限，あるいは不安定性などの機能障害を有する場合に適応となる．

人工関節の最大のメリットは，その確実な除痛効果と関節機能の改善にある．また後療法が短期間で済むことも大きな特徴であり，近年そのデザインや材質，手術器械，術式の改良により術後10〜15年を越える長期経過例においても90%以上の比較的安定した成績が報告されている．しかし人工関節は決して永遠の寿命を持つものではなく，緩みやポリエチレンの摩耗による耐用年数の問題のため，一般的に60歳あるいは65歳以上の患者に限定して手術が行われている．今後，より若年者に対する適応を拡大するためには，さらなる長期耐用性の向上が望まれるところである．

本稿では，現在我々が医工連携，産学連携を通して開発を目指している高機能かつ長期耐用性を有する次世代人工膝関節について解説する．

1．人工関節開発支援技術に関する研究

我々は，より機能的で長期耐用性を備えた次世代人工膝関節開発を行うためには，開発支援技術の確立が優先されるべきであるとの認識に立ち，A. 開発段階における力学的評価のための完全6自由度関節シミュレータ，B. 摩耗影響因子を考慮したコンピュータシミュレーションによる摩耗予測技術，C. 1方向X線透視画像によるイメージマッチングを適用した6自由度動態解析技術，の3つの支援技術を柱として研究を継続してきた．以下にそれぞれの支援技術について述べる．

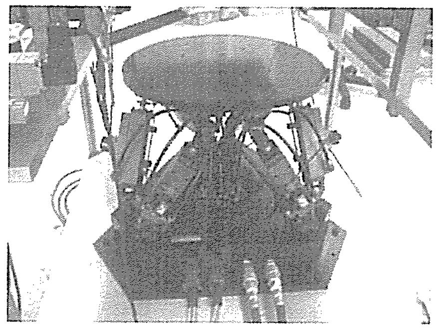

図1

A. 完全6自由度関節シミュレータ：膝関節シミュレータは，主に人工関節の摩耗試験を行うために用いるもので，生体材料の摩耗特性や形状デザインの評価には不可欠の機器である．シミュレータには，関節の複雑な運動を模擬するためにあらゆる方向への高い運動性と精度に加え，何百万回という反復運動を維持するための耐久性が要求される．しかし，現存のシミュレータではこれらの要求をすべて満たすものはない．われわれは生体関節の複雑な6自由度運動を再現するためにオリジナルの膝関節シミュレータを開発した．本シミュレータの特徴は下部構造にあり，6つの油圧アクチュエータをパラレルに配列している（図1）．この装置を用いることによって，生体の関節運動を完全にシミュレートすることが可能となり，従来のロボットアーム式のものと比較し，運動精度と耐久性が飛躍的に向上した．

B. コンピュータシミュレーションによる摩耗予測技術：摩耗は multifactorial な現象であり，摩耗を予測することは容易ではない．従来より摩耗予測はポリエチレン表面圧を重視し，有限要素法などの応力解析が行われてきたが，すべりのないところには摩耗は発生しない．そこで我々は，新しい摩耗予測パラメータとして面圧とすべり速度の積で定義される過酷度を考案した．過酷度は固有の人工膝関節形状と任意に与えた歩行パターンから導出することができる．現行の人工膝関節について過酷度を算出し，同一条件下で行った100万回の摩耗試験後の摩耗痕と比較してみると，摩耗部位は過酷度の分布と極めて近似していることがわかった．しかし，我々は，過酷度以外にも摩擦方向変化，すべり率，潤滑液暴露時間などが摩耗に影響を及ぼすことを見いだしている．例えば摩擦方向変化については，pin on plate による

摩耗試験の結果，単純な往復運動と比較し，摩擦方向が常に変化することにより急激な摩耗の増加が認められている．また潤滑液への暴露時間とは，一度摩擦された領域が潤滑液に浸され，再度 摩擦されるまでの時間と定義されるが，曝露時間が短いと，摩擦により剥離・損傷を受けた関節液の吸着膜が再修復されにくく，金属面の切削痕による摩耗の増加が予想される．摩擦試験では，曝露時間の短縮によりポリエチレンの比摩耗量が指数関数的に増加していた．

このような，面圧，すべり速度，摩擦方向変化，すべり率，暴露時間など摩耗に影響する多様な因子を考慮した複合パラメータによる摩耗予測を試みたところ，同一条件下における膝関節シミュレータによる摩耗試験の結果との比較において，実際の摩耗痕の深さとの相関が高まり，より高精度の摩耗予測が可能となっている．

C. イメージマッチングによる6自由度動態解析技術：生体内に挿入された人工膝関節が，日常生活動作の中で，どのような動態を示すのかを解析することは，術後の機能評価や将来のデザインの改良のために重要である．しかし，単純X線や透視では平面的な動きしか知ることができない．イメージマッチング法とは，一方向のX線写真から生体内での人工膝関節の複雑な動きを三次元的に解析するための手法である．具体的にはまず人工膝関節の大腿骨コンポーネントと脛骨コンポーネントの3次元形状データをそれぞれ測定し，その情報をコンピュータにストックしておく．次にそれぞれの3次元形状データをコンピュータ上で6自由度方向に動かしてその投影画像のライブラリーを作成し，一方向X線画像をこれらのライブラリと照合することによって，人工関節の3次元的な位置や姿勢を同定する．本法により任意の角度から人工関節の動態を0.3 mm，0.3°程度の高精度で観察することが可能となっている．

以上のような支援技術を駆使しながら，次世代人工膝関節開発を行っているが，具体的には，まず形状設計に基づき作成したプロトタイプに対し性能評価を行い，その結果を再び形状設計へフィードバックする．この段階で摩耗予測とシミュレータはお互いに補完的な役割を果たす．デザインが固まった段階で臨床応用を行い，一般的な臨床評価に加え，イメージマッチング法による生体内機能評価を行う．その結果は再び形状設計へとフィードバックされ，次世代モデル改良へ反映される．このようにこれらの支援技術を組み合わせることによって，より耐久性のある人工膝関節のデザイン開発が可能となる．

2．高機能次世代人工膝関節の開発（図2）

A. デザインの基本的コンセプト

人工関節の成績向上に伴い，患者側の要求はよりよい機能を持つ人工関節へと変化してきた．特に術後の屈曲可動域に関しては，日本人は正座の習慣があるために，深屈曲へのニーズは大きいものがある．近年では手術手技や後療法の改良によりある程度の深屈曲が可能となりつつあるが，通常110°から120°程度の屈曲が一般的で，正座に必要な155°と比較するとまだ大きな隔たりが存在する．

次世代人工膝関節の基本的なコンセプトは，日本人の膝関節の解剖学的形状に適合しながら，深屈曲に対応し，かつ低摩耗による長期耐用性を有するところにある．現行の大部分のインプラントは，深屈曲を許容するデザインではなく，たとえ深屈曲ができたとしても，大腿骨コンポーネント後顆のエッジとインサートが接触する可能性があり，ポリエチレンインサートの摩耗や破損が危惧される．そこで，次世代人工膝関節では後方顆部の厚みを増し，先端の曲率を大きくするというデザインを採用している．また正常膝がどのように深屈曲を実現しているのかをMRIを用いて解析したところ，深屈曲時おいて膝蓋骨が接触する顆間窩の形状は，外側顆が急峻にカーブし，外側よりに大きなスペースを形成しており，膝蓋骨は顆間窩に深く沈み込むことが明らかとなった．現行の人工膝関節は，深屈曲での適合性が不良であり，高い圧力が深屈曲を阻害すると思われる．次世代人工膝関節では，生体膝におけるこの関節形状を取り入れ外側顆を深く彫り込んでおり，この形状によって深屈曲位での膝蓋大腿関節の圧力を減じ，よりよい可動域の獲得につながると考えられる．

ポリエチレンインサートも大腿骨コンポーネントの形状設計に合わせて作成しており，歩行サイクルの中で荷重の大きな3つのphaseを選んで面圧を測定してみると，どのphaseにおいても現行の人工膝関節と比較し，次世代人工膝関節では

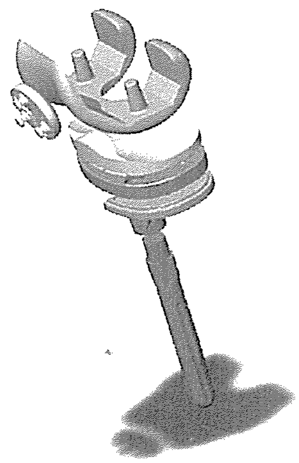

図 2

極めて低い接触圧が観察された．大腿骨コンポーネントを傾斜させた状態は lift off と呼ばれ，イメージマッチングで解析してみると実際の歩行中にも発生しているが，このような片当たりの厳しい条件下での面圧測定においても低い面圧が保たれていた．

B. コンピュータ支援手術

次世代人工膝関節の開発においては，これまで述べてきたようなデザイン開発と共に，手術術式も進化・改良していく必要がある．特に人工関節の手術において，コンポーネントを適切な位置に設置することは術後成績向上のための重要なポイントである．一般的に経験を積んだ術者は，経験の浅い術者と比較して，正確な手術が可能であるが，それでも結果にはある一定のばらつきが生じることは否めない．近年，より理想的な設置を目指す目的で，ナビゲーションシステムの開発と臨床応用が進んでいる．ナビゲーションシステムは術者の経験や勘に依存した場合のばらつきを極限まで小さくし，誰が行っても正確なコンポーネントの設置を可能にすることを目的としている．

原理はまず術前 CT，あるいは術中に透視装置を使うことにより，骨の形態情報を得ておく．その後，術中に骨表面に設置したマーカーを 3 次元カメラによりコンピュータに読み込み，実際の骨表面と骨形状データの位置合わせを行う．これらの操作により切骨面をリアルタイムにモニター上に表示することができ，術前計画どおりの切骨が可能となる．我々は，すでにナビゲーションシステムを導入し，実際の人工関節手術に用いている．屍体膝を使った精度実験では，従来法に比べ，明らかな精度向上を確認しており，臨床例においても，目的とする位置に正確に設置できることが明らかとなっている．

C. 最小侵襲手術（MIS）

MIS（minimally invasive surgery）とは，できるだけ小さな皮切で，生体組織の損傷を最小限にして行う手術のことで，人工股関節や人工膝関節においても，徐々に浸透しつつある術式である．従来の人工膝関節では，15〜20 cm ぐらいの大きな皮膚切開を使い，また大腿四頭筋を大きく切離して関節の展開を行っていたが，現在，我々が実施している MIS-TKA では，皮膚の切開は 8 〜10 cm 程度であり，また単に皮切が小さいだけではなく，大腿四頭筋への侵襲を最小限にして手術を行なっている．この方法により術後疼痛の軽減，リハビリテーション期間および入院期間の短縮化，また美容的にも優れるなど多くの利点を確認している．将来はナビゲーションシステムとの融合をはかり，より低侵襲で，より正確な術式の確立を目指していく予定である．

おわりに

人工関節は高度に破壊された関節の機能再建術として，すでに患者に大きな福音をもたらしているが，人工関節にはまだ進化の余地が残されている．今後も，より機能的で，低侵襲，低摩耗，長期耐用性を有する人工関節の開発を目指して，弛まない努力が要求される．

我々は，これまで培ってきた開発支援技術を駆使し，長期耐用性を有する深屈曲対応型人工膝関節モデルを完成し，今年度中に臨床応用を開始する計画である．