Case series report of navigation-based *in vivo* knee kinematics in total knee arthroplasty with a gradually reducing femoral radius design

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**ABSTRACT**

**Background:** Simulations show that paradoxical anterior femoral slide in conventional dual radius total knee arthroplasty (TKA) is initiated by sudden reduction of the femoral radius from distal to posterior. Therefore, we hypothesized that a new TKA prosthesis design with a gradually reducing femoral radius may minimize the anterior slide in navigation-based *in vivo* knee kinematics. The purpose of this study was to compare the kinematics of TKA *in vivo* using a prosthesis with a gradually reducing radius, in comparison with the conventional dual radius design.

**Methods:** A retrospective case series report was performed for 12 knees with osteoarthritis using a CT-free navigation system. Six knees received TKA using a prosthesis with a gradually reducing femoral radius (Attune CR) and the other 6 knees underwent TKA using a conventional dual radius design (PFC CR). Anterior-posterior (AP) displacement of the medial and lateral femoral condyles relative to the tibia, and kinematic patterns of the femur throughout the range of motion were compared between the groups.

**Results:** The average AP displacement in the Attune CR group indicated no paradoxical anterior movement of both condyles, and kinematic data showed a medial pivot pattern. In contrast, AP displacement in the PFC CR group indicated that both condyles showed paradoxical anterior movement, and kinematically both condyles moved in the same manner, showing a parallel motion pattern.

**Conclusion:** TKA using a prosthesis with a gradually reducing radius minimized paradoxical anterior slide in navigation-based *in vivo* knee kinematics.

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**1. Introduction**

Various designs of prostheses have been proposed for improvement of the range of knee motion and other outcomes after total knee arthroplasty (TKA). Assessment of preoperative and postoperative kinematics is important for understanding of the current status and outcomes in TKA. In a comparison of postoperative kinematics in posterior cruciate ligament-retaining (CR) and -substituting (PS) TKA, Victor et al. found that CR knees showed greater paradoxical anterior femoral translation of the femoral condyle [1]. In a study of kinematics of 811 knees treated with 33 different types of TKA, Dennis et al. also found that paradoxical anterior femoral translation was most likely to occur in CR knees during deep flexion [2]. In the same study, only 55% of all knee groups were found to have a medial pivot kinematic pattern, which is common in normal knees, during deep knee bending motion [2]. Banks et al. compared the kinematics of five implant designs and found that knee motion was associated with implant constraint as the implant moved on the guided surface [3].

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In studies using navigation-based intraoperative kinematics, Baier et al. reported slight mid-flexion instability in CR compared with PS TKA [4], and Massin et al. detected paradoxical displacements in hyper congruent prostheses [5]. Thus, intra- and postoperative kinematics of TKA vary depending on the model and type of prostheses, and all TKA procedures do not give similar knee kinematics to those of normal knees [6,7]. Paradoxical anterior femoral translation in the femoral condyle against the tibia during mid-flexion is observed most frequently in CR TKA, and such anterior instability during mid-flexion might reduce the satisfaction of patients after TKA.

A study using cadaveric knees by Clary et al. indicated that a TKA prosthesis with a gradually reducing femoral radius improved this anterior instability [8]. In this study, we examined if this phenomenon occurs in vivo. Thus, the objective of the study was to use intraoperative kinetic analysis with a navigation-based system to evaluate anterior instability and kinematic patterns during mid-flexion in TKA with a prosthesis with a gradually reducing radius, compared with conventional TKA with a J curve in the femoral component.

2. Materials and methods

This is a retrospective case series report at single centre of consecutive patients. We used the PROCESS guidelines for reporting of case series in surgery. This guideline consisted of an eight item checklist that would improve the reporting quality of surgical case series [9]. The subjects were 12 patients with varus knee osteoarthritis (OA) of mean age 75 ± 8.1 years who underwent initial TKA using a CT-free navigation system (Kobilri Knee Brain Lab) at our hospital. Exclusion criteria was varus knee OA. Exclusion criteria was valgus Knee OA, rheumatic arthritis and trauma arthritis. Seven patients had a medical treatment of high blood pressure, and 3 patients had a medical treatment of diabetes. A patient with depth vein thrombosis wasn’t before operation. Of the 12 knees, 6 were implanted with the Attune CR (DePuy, Warsaw, IN), a new TKA prosthesis design with a gradually reducing femoral radius, and 6 knees were implanted with the PFCΣ CR (DePuy, Warsaw, IN), a conventional design with a J curve in the femoral component. There were no significant differences in preoperative characteristics between the groups (Table 1). All patients underwent TKA by a same surgical team with more than twenty years experience. This navigation system for software – guided surgery gives visual guidance allowing less invasive surgery and better alignment of implants. The patients carried out an operation using tourniquet by general anesthesia. The measured resection technique was used. After exposing the knee, two passive optical reference arrays were attached on the distal femur and the proximal tibia. After approval of the centre of the hip joint by circumdiction, the required anatomical landmarks (femoral epicondyles, anterior femoral cortex, medial and lateral malleolus, tibial plateau magnitude and anterior tibial cortex) were acquired. The femoral external rotation angle was defined as the angle that 2° as the remaining cartilage of the epicondylar axis of the femur were subtracted from the angle between the clinical epicondylar axis and posterior condylar axis. After placement of the implant, the tourniquet was released to measure the anterior-posterior (AP) shift of the femoral condyle against the tibia from full extension to 130° of knee flexion and the resulting kinematic patterns of the internal and lateral condyles of the femur. During this measurement, the knee was bent by slightly raising the heel to lift the femur. The AP shift and rotation patterns of the medial and lateral condyles were compared between the Attune CR and PFCΣ CR groups. There were no complications of an operation including pin-site fracture. This study was conducted with approval from the ethics committee of Showa university Fujigaoka hospital (No.2011029). And this study was registered with Research Registry (No.2235).

3. Results

Regarding the AP-shift, the anterior sliding movement of the medial and lateral condyles during mid-flexion was less and paradoxical anterior femoral translation of the medial condyle of the femur was not observed in the Attune CR group. Compared with the medial condyle of the femur, the lateral condyle significantly moved posteriorly (Fig. 1). In contrast, in the PFCΣ CR group, anterior sliding movement of the medial and lateral condyles was observed (Fig. 2). In a cadaver study, Digennaro et al. showed that posterior movement of the medial and lateral condyles was greater in BCS TKA [10]. Dennis et al. [2] and Baier et al. [4] confirmed that the anterior instability during mid-flexion reported by Victor et al. [1], which is due to paradoxical anterior femoral translation of the medial condyle, is commonly seen in CR TKA.

Regarding the design of femoral components, the radius of the J curve of the femoral component in conventional PFCΣ CR TKA changes only 3 times. In contrast, in the Attune CR, the morphology of the femoral component is similar to that of the posterior part of the femur, in which the radius gradually reduces, which prevents paradoxical anterior translation during mid-flexion and improve stability. In a cadaver study, Clary et al. [8] showed that paradoxical anterior translation during mid-flexion occurred at the site where the femoral radius suddenly reduced in the conventional PFCΣ CR, and was improved using Attune CR TKA with a gradually reducing femoral radius. This improvement was caused by the enhanced compatibility of the insert and femoral component. The current study of in vivo implantation showed a similar phenomenon (Fig. 5). These findings suggest that paradoxical anterior translation during mid-flexion can be limited by the femoral implant design and by enhancement of the compatibility of the insert and femoral component.

Table 1

| Patient demographics in the Attune CR and PFC Σ CR groups. | Attune CR (n = 6) | PFC Σ CR (n = 6) |
| --- | --- | --- |
| Age (years) | 74.1 ± 8.5 | 75.5 ± 7.9 |
| Gender (male/female) | 0/6 | 0/6 |
| Side (right/left) | 2/4 | 3/2 |
| BMI (kg/m²) | 25.1 ± 3.5 | 24.8 ± 4.1 |
| Initial alignment (varus degree) | 9.4 ± 3.7 | 8.5 ± 6.0 |

There were no significant differences in demographics between the two groups.
Freeman et al. [11] and Tanifuji et al. [12] described normal knee kinematic patterns in which the medial condyle of the femur hardly moved anteroposteriorly from 0 to 120° and showed medial pivot motion from 120° flexion to full flexion, with bicondylar rollback motion. Dennis et al. [2] found varying patterns in TKA, with only 55% of cases showing a medial pivot kinematic pattern. In a study using a CT-based navigation system, Nishio et al. found TKA kinematic patterns including medial pivot, lateral pivot and parallel...
motion, and showed significantly better postoperative knee flexion angles and patient-based outcomes in the group with a medial pivot pattern during surgery [13]. Matsuzaki et al. also reported that tibial internal rotation during surgery using a navigation system was an important factor influencing the postoperative knee flexion angle [14]. Thus, many reports indicate that stable intraoperative kinematics are likely to result in improved postoperative clinical outcomes.

There were several limitations in this study, including that TKA kinematics were measured unloaded under general anesthesia and that the subjects and surgical techniques might have influenced the results. Therefore, further studies are required to evaluate the clinical outcomes of the Attune CR.

5. Conclusion

Instability during mid-flexion did not occur in navigation-based in vivo knee kinematics in TKA performed using a prosthesis with a...
gradually reducing radius, and the kinematic pattern was a medial pivot pattern. Further studies are required to evaluate the clinical outcomes of the new design in TKA.

**Ethical approval**

The Ethical Approval was given by Chairperson of the Institutional Review Board of Showa University Fujigaoka Hospital. The reference number is 2011029.

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**Author contribution**

Study design: Hiroshi Takagi.
Data collections: Hiroshi Takagi, Soshi Asai, Atsushi Sato, Humiyoshi Kawashima.
Data Analysis: Hiroshi Takagi, Masahiko Maekawa, Koji Kanzaki.
Writing: Hiroshi Takagi.

**Conflicts of interest**

Conflicts of interest: none.

**Research registration unique identifying number (UIN)**

UIN is 2235.

**Guarantor**

Hiroshi Takagi.

**Disclosure statement**

The authors have nothing to disclose.

**Competing interests**

The authors declare that they have no competing interests.

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