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In vivo kinematic analysis of posterior-stabilized total knee arthroplasty for the valgus knee operated by the gap-balancing technique

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ABSTRACT

Background: Most in vivo kinematic studies of total knee arthroplasty (TKA) report on the varus knee. The objective of the present study was to evaluate in vivo kinematics of a posterior-stabilized fixed-bearing TKA operated on a valgus knee during knee bending in weight-bearing (WB) and non-weight-bearing (NWB).
Methods: A total of sixteen valgus knees in 12 cases that underwent TKA with Scorpio NRG PS knee prosthesis and that were operated on using the gap balancing technique were evaluated. We evaluated the in vivo kinematics of the knee using fluoroscopy and femorotibial translation relative to the tibial tray using a 2-dimensional to 3-dimensional registration technique.
Results: The average flexion angle was 111.3° ± 7.5° in WB and 114.9° ± 8.4° in NWB. The femoral component demonstrated a mean external rotation of 5.9° ± 5.8° in WB and 7.4° ± 5.2° in NWB. In WB and NWB, the femoral component showed a medial pivot pattern from 0° to midflexion and a bicondylar rollback pattern from midflexion to full flexion. The medial condyle moved similarly in the WB condition and in the NWB condition. The lateral condyle moved posteriorly at a slightly earlier angle during the WB condition than during the NWB condition.
Conclusions: We conclude that similar kinematics after TKA can be obtained with the gap balancing technique for the preoperative valgus deformity when compared to the kinematics of a normal knee, even though the magnitude of external rotation was small. Level of evidence: IV.

1. Introduction

In total knee arthroplasty (TKA), the preoperative status of the knee is reported to influence post-operative clinical results and knee deformity is one of the most important factors to influence the post-operative results [1]. TKA for the valgus knee deformity is a surgical challenge. The combination of bony deformity and soft tissue abnormalities complicates TKA. To perform deep knee bending after TKA, it has been reported that a bicondylar rollback motion and external rotation of the femoral component relative to the tibial component are desirable [2]. Previous kinematic analyses demonstrate that in vivo kinematic patterns in subjects after TKA vary considerably [3], and suggest that TKA patients often display a different pattern from the normal knee [4–6]. Therefore, analysis of kinematic patterns of TKA performed on valgus knees provides important information. To our knowledge there are a few prior studies examining knee kinematics with valgus knees [7,8].

The Scorpio Non-Restrictive Geometry (NRG: Stryker Orthopedics, Mahwah, NJ) is a recent product whose midterm clinical longevity has been reported to be excellent [9,10]. In vivo kinematics of this implant was reported. Both the posterior-stabilized (PS) and cruciate-retaining (CR) design showed posterior roll back and external rotation. The PS design showed external rotation with medial pivot and the CR design showed external rotation with central or medial pivot [11–13].

Furthermore, a variety of knee motions are necessary to perform walking, stair climbing, squatting and kneeling in daily life. These motions accompany knee flexion in weight-bearing (WB) and non-weight-bearing (NWB) conditions.

The purposes of the current study are: (1) to analyze the in vivo kinematic motion of Scorpio NRG PS TKA, and (2) to compare kinematic

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patterns between WB and NWB knee flexion in knees with preoperative valgus deformity.

2. Materials and methods

Sixteen valgus knees in 12 cases that underwent TKA with Scorpio NRG PS knee prosthesis were assessed in this study. All components were well fixed according to radiographic evaluation. The mean age at the time of operation was 72.5 years (range, 63–77 years old). There were 9 knees in 7 patients with osteoarthritis, and 7 knees in 5 patients with rheumatoid arthritis. All subjects exhibited severe valgus deformities and rated as advanced stage. Patient demographics are listed in Table 1. All the surgery was performed by or under the supervision of one senior author (KS). Institutional review board approval was obtained as well as informed consent from all patients participating in this study.

Surgery was performed through a midvastus approach. Distal femur and proximal tibia were cut perpendicular to the mechanical axis of each bone. After excision of the menisci and cruciate ligaments, ligament imbalance in the coronal plane was assessed using seesaw type JDK offset balancer (Stryker, Mahwah, NJ) in extension. Lateral release was performed in extension. Iliotibial bundle (ITB) was released from Gerdy tubercle then posterolateral capsule was released at the level of the proximal tibial cut surface in all cases. In four knees, pie-crust ITB [14] from inside-out was added at 1 cm above the joint line until an appropriate lateral and medial balance was obtained. The amount of the resection from the posterior femoral condyle was calculated in order to make the extension and the flexion gap equal. In this step, joint traction force was set at 40 lb to decrease the error due to the creep elongation of surrounding soft tissue. The intraoperative gap in the central part of the knee and gap inclination were measured in extension and 90° flexion with the patella inverted (Table 1). At the time of follow-up for the kinematic analysis, we evaluated lateral laxity on X-ray applying a 20 N force from each side of the joint in extension. We measured the angle between femoral and tibial component at the joint space. Medial opening with valgus stress averaged 3.8 ± 1.6° and lateral opening with varus stress averaged 2.2 ± 1.2°.

Each patient was asked to perform sequential deep knee bends under both WB and NWB conditions. The motion from full extension to maximum flexion was performed under fluoroscopic monitoring in the sagittal plane. Under the NWB condition, the patient sat on a chair and was asked to perform active knee bending.

Successive knee movements were recorded as serial digital X-ray images (1280 × 1024 bits/pixels, 15-Hz serial spot images as a Dicom file) using a 17-in digital image intensifier system (Axion Luminos, Siemens, Germany) and pulsed X-ray beams of 1 to 2 ms. The 3D positions of the Scorpio NRG prosthesis were computed at 10° flexion intervals using a 2D/3D registration technique, which used computer-assisted design (CAD) models to reproduce the positions of the femoral and tibial components from calibrated single-view fluoroscopic images.

Table 1
Patient demographics.

Parameters	Mean	SD	Range
Preoperative FTA (°)	156.1	4.2	152–170
Postoperative FTA (°)	174.5	2.6	171–177
α Angle (°)	96.7	2.3	93–102
β Angle (°)	88.9	1.2	87–92
γ Angle (°)	3.6	2.9	0–8
δ Angle (°)	86.4	1.3	84–88
Intraoperative gap measurement			
Extension gap (mm)	24.2	2.3	20–27
Flexion gap (mm)	23.9	2.4	20–29
Gap inclination in extension (°)[a]	2.3	1.5	0–5
gap inclination in flexion (°)[a]	0.6	2.8	5 to −5

FTA: femorotibial angle.
[a] Medial opening is positive.

The registration algorithm proposed by Zuffi et al. [15] was used in the current study. Experimental accuracy of the relative motion between metal components was <0.5° in rotation and <0.4 mm in translation. We evaluated the range of motion (ROM) and axial rotation angles between the femoral and tibial components. In the femoral coordinate system, the origin was defined as the center of gravity for the component. In the tibial coordinate system, the origin was defined as the center of the tibial surface. Anteroposterior translation of the nearest point between the femoral component and tibial polyethylene insert for the medial and lateral sides were evaluated. Axial femoral rotation was defined as positive for external rotation.

On the medial and lateral sides, the nearest point of the femoral component relative to the tibial insert as the center of quasi contact was determined by calculating the nearest distance between the surfaces of the CAD models. Anteroposterior positions of the femoral component anterior to the tibial insert were designated as positive and posterior positions were designated as negative. All data were expressed as the mean ± SD (range, minimum to maximum).

The nonparametric Mann–Whitney test was used to compare AP displacement of the medial and lateral femoral condyles. Values of <.05 were considered statistically significant.

3. Results

3.1. Kinematics during weight bearing

Under WB conditions, the mean full extension angle was 0.75° ± 6.6° (range, −9° to 13.8°) between femoral and tibial implants and the mean ROM was 110.6° ± 7.8° (range, 96.2° to 121.2°). Regarding axial rotation of the femoral component relative to the tibial component, the mean axial rotation was −0.09° ± 3.9°(range, −5.1° to 7.3°) at 0°, and 4.8° ± 7.1° (range −4.7° to 15.2°) at 110° of knee flexion (Fig. 1). The femoral component exhibited gradual external rotation from extension to flexion. The mean range of axial rotation during the flexion cycle was 5.9° ± 5.8° (range, −3.4° to 18.1°). All but two knees exhibited external rotation patterns and 4 of 16 knees revealed more than 10° of external rotation during the knee flexion cycle. The mean anteroposterior translation is shown in Fig. 2-A. Under the WB condition, the mean medial contact point at full extension was −3.2 mm ± 1.9 mm. The average nearest medial point moved 0.49 mm ± 1.3 mm anteriorly to reach −2.7 mm ± 1.7 mm (range −6.8 mm to 0.16 mm) at 60° of knee flexion. From 60° to full flexion, the average nearest point moved 6.5 mm ± 2.6 mm posteriorly to reach −9.2 mm ± 2.7 mm (range −13.5 mm to −3.5 mm). The mean lateral contact point at full extension was −2.5 mm ± 2.6 mm. The average nearest lateral point moved 3.4 mm ± 2.6 mm posteriorly to reach −5.9 mm ± 3.0 mm (range −13.3 mm to −1.8 mm) at 60° of knee flexion. From 60° to full flexion, the average nearest point moved 7.9 mm ± 2.5 mm posteriorly to reach −13.8 mm ± 2.8 mm (range −20.5 mm to −10.7 mm). In the WB condition, the femoral component showed a medial pivot pattern from 0 to 70° of knee flexion and the femoral component showed a bicondylar rollback pattern from 70° to 110° (Fig. 3).

3.2. Kinematics during non-weight bearing

Under NWB conditions, the mean full extension angle was −0.8° ± 6.4° (range, −10.4° to 12.1°) and the mean ROM was 115.7° ± 6.3° (range, 105.2° to 127.2°). The mean axial rotation was 0.21° ± 4.1° (range −8.4° to 8.2°) at 0°, and 7.3° ± 5.3° (range

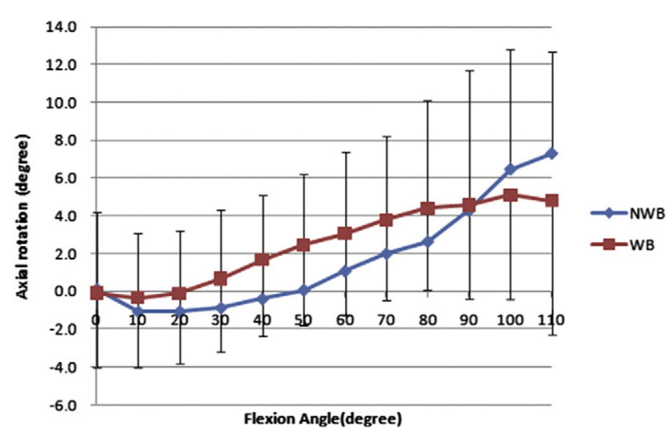

Fig. 1. Femoral component axial rotation for the tibial tray (mean ± SD) during knee bending in WB and NWB states. Positive values represent external rotation.