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Gait Analysis of Patients with a Rotating Hinge Knee Prosthesis after Revision Total Knee Arthroplasty

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Abstract

Background: The number of revision total knee arthroplasty (TKA) procedures performed worldwide is increasing. The rotating hinge knee type (RHK) prosthesis is used for revision TKA. There has been no report on motion analysis of patients with RHK prosthesis. Therefore, this study aimed to clarify the kinetics and kinematics of the lower limb during gait in patients who have undergone revision TKA with an RHK prosthesis.

Methods: This cross-sectional study assessed patients who underwent revision TKA with an RHK prosthesis (R-RHK; 14 patients, 24 knees), those who underwent unilateral primary TKA with a cruciate-retaining (CR) type prosthesis (uniCR; five patients, five knees), and those who underwent bilateral primary TKA with a CR type prosthesis (bilCR; 10 patients, 20 knees). Their comfortable gait was analyzed. Spatiotemporal parameters and knee joint angle and moment were calculated. The knee joint angle and tibial translation were compared among the three groups using analysis of variance and a post-hoc Tukey test. The knee adduction moment in the groups were compared by performing analysis of covariance after controlling for gait speed.

Results: Gait speed was significantly lower in the R-RHK group than in the other groups. The knee joint angle, knee adduction moment, and tibial translation were not different between the R-RHK, uniCR, and bilCR groups during gait and at the beginning of the stance phase.

Conclusion: The gait of patients who have undergone revision surgery using an RHK prosthesis because of aseptic loosening may have the same biomechanics as that of patients who have undergone primary TKA using a different type of prosthesis.

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Introduction

Total knee arthroplasty (TKA) is the treatment of choice for severe knee joint osteoarthritis (KOA). There is a wide variety of prostheses available for TKA. Surgeons determine the appropriate prosthesis for TKA based on the grade of deformity of the knee arthritis. A bicruciate-retaining type of implant can preserve the anterior cruciate ligament and posterior cruciate ligament [1,2]. A cruciate-retaining (CR) type of implant is substituted for posterior cruciate ligament sufficiency [3]. A posterior-stabilized type of implant, with a constrained condylar design to address collateral ligament insufficiency, is substituted for the posterior cruciate ligament [4,5]. An Australian registry reported that the frequencies of usage of CR and posterior-stabilized implants are 72% and 28%, respectively [6]. The CR type implant is selected more frequently than the posterior-stabilized type implant worldwide [6]. A rotating-hinge knee (RHK) prosthesis is used for the treatment of global instability or severe bone loss around the knee [7,8]. Bolanos described gait analysis parameters for patients treated using CR and posterior-stabilized total knee designs [9]. However, there has been no report on the motion analysis of patients with RHK prosthesis. Thus, the kinetics and kinematics of the gait of patients who have undergone RHK prosthesis have never been analyzed.

The number of revision TKAs performed worldwide is increasing along with increasing life expectancy [10]. The main reasons for revision TKA are septic loosening, polyethylene wear, pain, instability, stiffness, component malposition, patellar maltracking, and aseptic loosening [11-15]. Approximately 25% of revision TKAs were due to aseptic loosening [16]. Hildin et al. reported that aseptic loosening was associated with increased knee adduction moment (KAM) during gait [17].

The NexGen RHK (Zimmer, Warsaw, Ind, USA) is a modern modular rotating hinge design. It has the characteristics of included modular augments to address bone defects and modular fluted canal filling stems, provides more reliable alignment and additional fixation, allows 25° each of internal and external rotations of the polyethylene inlay, and control the tibial translation (anteriorly to posteriorly and laterally to medially) [8]. The RHK prosthesis has been used in revision TKA [8]; however, its motion analysis has never been reported.

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Therefore, the purpose of this study was to clarify the kinetics and kinematics of the lower limb during gait in patients who underwent revision TKA using an RHK prosthesis. The knee varus angle in the stance phase during gait is not different between patients who have undergone revision TKA using an RHK prosthesis and those who have undergone primary TKA. Thus, we hypothesized that the knee varus angle and KAM of patients who received the revised TKA selected for RHK prosthesis are the same as those of patients who received the primary TKA selected for CR implant.

Materials and Methods

Study design and setting

This study used an in vivo cross-sectional design. The study was reviewed and approved by the review board of Tokyo Metropolitan University (approval number: 18031). All participants provided signed informed consent before participating in the study.

Study participants

The patients were those who underwent revision TKA after primary TKA. The inclusion criteria were as follows: 1) patients [R-RHK] who underwent revision TKA using an RHK prosthesis for aseptic loosening, 2) a time lapse of 6 months or more since revision TKA, and 3) patients who could walk independently. NexGen RHK. The inclusion criteria for the control group were as follows: 1) patients who underwent primary TKA using the CR type prosthesis (with or without anterior-stabilizing bearing; unilateral primary TKA with the CR type prosthesis [uniCR] and bilateral primary TKA with the CR type prosthesis [bilCR]), 2) a time lapse of 6months or more since TKA, and 3) patients who could walk independently. Patients who underwent primary TKA using the CR type prosthesis were included in the control group because the CR type was the most common thigh component worldwide [6]. The bilCR group was included alongside the uniCR group because cases of simultaneous bilateral TKA have increased. In both groups, patients with rheumatoid arthritis or other conditions that affect motor function such as neurologic diseases were excluded. There were six participants in the R-RHK group. The control group included 14 participants (24 knees):five(5 knees) in the uniCR group and 10 (20 knees) in the bilCR group. Participants' demographics are presented in Table 1.

Procedures

All participants were assessed at a comfortable gait pace using a three-dimensional motion analysis system (Vicon Nexus; Oxford Metrics, London, UK) with 10 cameras operating at a sampling rate of 100 Hz. The ground reaction force was captured using two force plates (Kisler Japan, Tokyo, Japan) at a sampling rate of 1,000 Hz. Fifty-six 9-mm infrared reflective markers were attached to anatomical locations using the point cluster method. Markers were placed on the bilateral anterior superior iliac spine, posterior superior iliac spine, thigh clusters, shank clusters, calcaneus, lateral malleolus, and head of the second metatarsal bone. In addition, markers were attached to the medial condyle of the thigh and medial malleolus of each participant. Thigh clusters consisted of the greater trochanter and lateral femoral epicondyle markers plus nine markers evenly distributed across the anterior and lateral thigh. Shank clusters consisted of the lateral condyle marker plus six additional markers evenly distributed across the anterior and lateral shank. Patients were asked to walk at their self-selected speed along an 8-m walkway. Data on the participant's foot landing on the center of the force plate without any interference to their gait were collected. For each trial, gait events were detected using vertical ground reaction force data to determine the initial foot contact and toe-off.

Outcome measures

The spatiotemporal parameters (gait speed, cadence, step length, and step width) were calculated using Plug-in Gait (Vicon Motion Systems, Oxford, UK). A standard lower extremity musculoskeletal model was created using SIMM 7.0 (SIMM; Software for Interactive Musculoskeletal Modeling MusculoGraphics, Santa Rosa, CA) based on the three-dimensional data. The model included the pelvis, sacrum, femur, tibia, fibula, patella, talus, calcaneus, and metatarsal bones, along with 36 muscles of the lower extremity. A segment of the pelvis and both thighs, shanks, and feet were created from these bones. Each segment was joined by the hip joints, knee joints, ankle joints, and subtalar joints. The knee joint observed in this study had 6 degrees of

	R-RHK n=6, 6 knees	uniCR n=5, 5 knees	bilCR n=10, 20 knees			
	Mean± SD (95% CI)	Mean± SD (95% CI)	Mean± SD (95% CI)	F value	P-value	η^2
Age (years)	73.00±6.83 (62.13–83.87)	67.67±0.58 (66.23–69.10)	71.67±5.13 (58.91–84.41)	0.22	0.81	0.02
Postsurgery TKA (months)	22.00±17.37 (0.42–43.58)	9.60±3.28 (5.52–13.69)	10.80±2.68 (7.47–14.13)	3.67	0.05	0.24
The number of kneesusing AS bearing	-	3/4 knees	12/20 knees	-	-	-
Height (cm)	150.88±5.32 (144.26–157.50)	154.20±8.00 (144.26–164.14)	145.92±4.60 (140.21–151.63)	1.22	0.31	0.11
Weight (kg)	65.28±9.15 (53.92–76.64)	63.20±7.39 (54.03- 72.38)	58.00±10.40 (45.09–70.92)	0.03	0.98	0.00
BMI (kg/m^2)	28.56±2.47 (25.49–31.63)	26.54±1.72 (24.40–28.67)	27.20±4.54 (21.26–32.84)	0.57	0.58	0.05

Table 1: Participant demographics of each group.

$p<0.05$: statistically significant difference; TKA: total knee arthroplasty; AS bearing: anterior- stabilizing bearing; BMI: body mass index; R-RHK: revision TKA due to aseptic loosening with the rotator hinge knee type; uniCR: unilateral primary TKA with the cruciate retaining type; bilCR: bilateral primary TKA with the cruciate retaining type; CI: confidence interval.

freedom (flexion/extension, adduction/ abduction, internal rotation/ external rotation) and one translation motion (anterior/posterior).

Using this model, the following items during the stance phase of gait were calculated: maximum knee flexion/extension, maximum varus/valgus, maximum internal rotation/external rotation angle, and KAM at the first peak. The amounts of change in the rotation angle and tibial translation (anterior-posterior) were calculated from the initial contact to loading response in the stance phase. In this study, a leg was counted as one sample to investigate the kinetics and kinematics of a leg.

Statistical analysis

The normality of each variable's distribution was determined by a histogram and the Shapiro-Wilk normality test. Participants' demographics, the spatio-temporal parameters, knee joint angles, and tibial translations were compared among the three groups, the R-RHK, uniCR, and bilCR groups, by using analysis of variance (ANOVA) and the post-hoc Tukey test. KAM was compared between the groups by using analysis of covariance (ANCOVAs) controlling for gait speed. All statistical analyses were performed using SPSS 23.0 J (IBM Corp., Armonk, NY, USA). The significance level was set at 5%.

Results

Normality was confirmed on all parameters. The age, height, weight, and body mass index were not significantly different among the three groups. Among the spatiotemporal parameters, gait speed was significantly slower in the R-RHK group than in the uniCR and bilCR groups (p<0.01; R-RHK: 0.8±0.06 m/s, uniCR: 1.0±0.04 m/s, bilCR: 1.1±0.2 m/s), and step length was significantly narrower in the R-RHK group than in the uniCR and bilCR groups (p= 0.01; R-RHK: 43.3±6.4 cm, uniCR: 54.5±3.7 cm, bilCR: 52.0±6.0 cm; Table 2). The knee joint angles were not significantly different among the groups (Table 3 and Figure 1-3). KAM controlled for gait speed was not significantly

	R-RHK	uniCR	bilCR			
	Mean± SD (95% CI)	Mean± SD (95% CI)	Mean± SD (95% CI)	F value	P-value	η^2
Gait speed (m/s)	0.79±0.02 (0.77–0.82)	0.99±0.04 (0.94–1.05)	1.02±0.14 (0.80–1.23)	9.31	<0.01	0.47
Cadence (steps/min)	114.50±15.54 (89.76–139.24)	112.00±2.44 (108.10–118.90)	119.75±12.50 (99.86–139.64)	1.31	0.29	0.11
Step length (cm)	43.50±7.55 (31.49–55.51)	54.50±3.70 (48.62–60.38)	52.14±5.53 (48.94–55.34)	6.69	0.01	0.39
Step width (cm)	17.00±3.56 (11.34–22.66)	14.67±4.08 (10.38–18.95)	14.67±4.37 (10.08–19.25)	2.48	0.11	0.18

Table 2: Spatio-temporal parameters of each group.
p<0.05: statistically significant difference; R-RHK: revision TKA due to aseptic loosening with the rotator hinge knee type; uniCR: unilateral primary TKA with the cruciate retaining type; bilCR: bilateral primary TKA with the cruciate retaining type; CI: confidence interval.
Among the spatiotemporal parameters, gait speed in the R-RHK group was significantly slower and step length in the R-RHK group was significantly longer than those in the uniCR and bilCR groups.

	R-RHK	uniCR	bilCR			
	Mean± SD (95% CI)	Mean± SD (95% CI)	Mean± SD (95% CI)	F value	P-value	η^2
Maximum flexion angle (deg)	40.24±7.07 (31.47– 49.01)	41.21±9.20 (29.78–52.63)	35.42±7.13 (26.57–44.28)	0.24	0.79	0.01
Minimum flexion angle (deg)	9.30±8.91 (-1.76–20.36)	9.61±4.73 (3.73–15.50)	5.20±5.74 (-1.93–12.33)	0.92	0.41	0.05
Maximum varus angle (deg)	1.65±2.14 (-1.76–5.06)	-0.64±2.75 (-5.01–3.72)	1.50±1.81 (-1.39–4.39)	0.55	0.58	0.03
Maximum inner rotation angle (deg)	-2.11±15.13 (-26.20–21.98)	-8.98±4.75 (-16.54–-1.41)	-5.86±7.18 (-17.28–5.57)	1.17	0.32	0.06
Maximum external rotation angle (deg)	10.99±8.57 (-2.67–24.60)	15.37±5.09 (7.26–23.47)	11.78±5.80 (2.54–21.01)	1.41	0.26	0.07
Amount of rotation angle (deg)	5.60±3.30 (0.35–10.86)	6.40±2.88 (1.81–10.98)	5.92±2.47 (1.99–9.85)	0.26	0.77	0.01
KAM(Nm/kg)*	0.55±0.34 (0.18–0.57)	0.37±0.16 (0.18–0.57)	0.35±0.11 (0.22–0.48)	0.74	0.71	0.07

Table 3: Kinetics and kinematics data during gait.
p<0.05: statistically significant difference; R-RHK: revision TKA was due to aseptic loosening with the rotator hinge knee type; uniCR: unilateral primary TKA with the cruciate retaining type; bilCR: bilateral primary TKA with the cruciate retaining type; CI: confidence interval; KAM: maximum knee adduction moment during stance phase
The knee joint angles were compared among the three groups, the R-RHK , the uniCR, and the bilCR groups by using analysis of variance (ANOVA) and the post-hoc Tukey test.
*KAM was compared inter groups by analysis of covariance (ANCOVAs) controlling for gait speed.

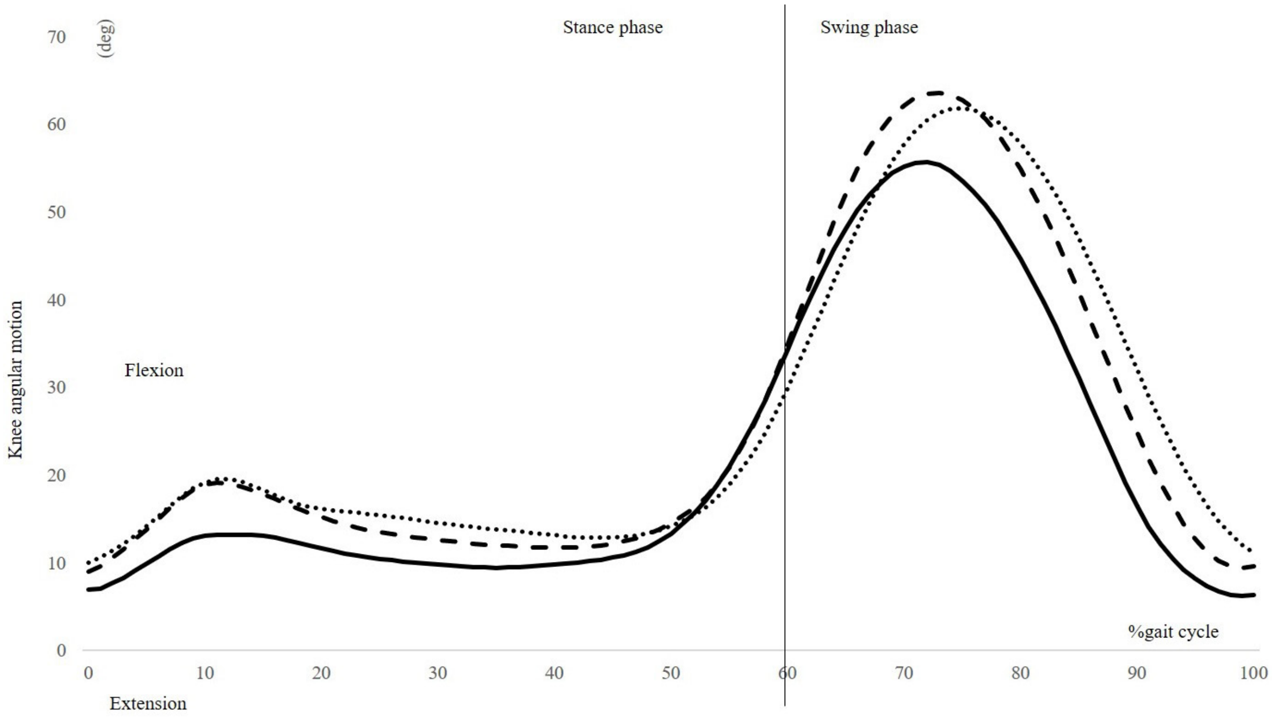

Figure1: Knee angular motion (sagittal plane).
The continuous, dash, and dot lines represent R-RHK, uniCR, and bilCR, respectively.
Abbreviations: R-RHK: revision total knee arthroplasty with a rotating hinge knee type prosthesis; uniCR: unilateral primary total knee arthroplasty with a cruciate-retaining prosthesis; bilCR: bilateral primary total knee arthroplasty with a cruciate-retaining prosthesis.

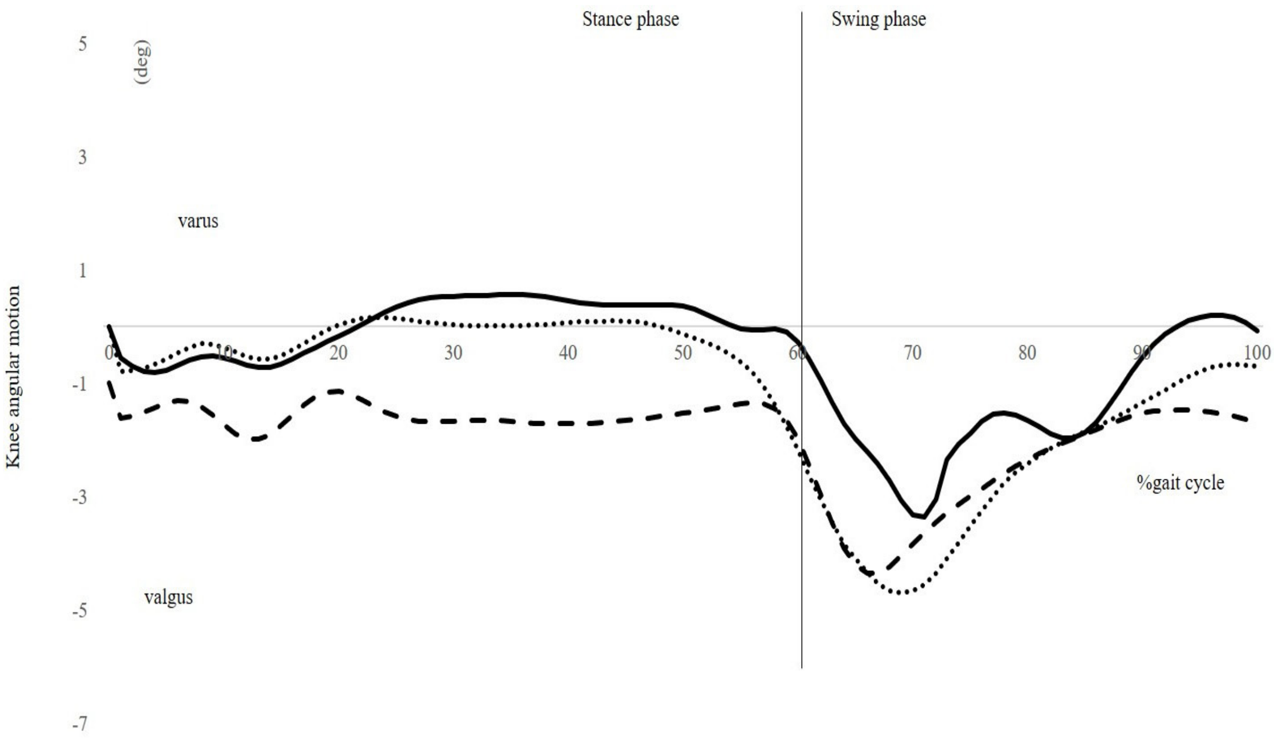

Figure 2: Knee angular motion (frontal plane).
The continuous, dash, and dot lines represent R-RHK, uniCR, and bilCR, respectively.
Abbreviations: R-RHK: revision total knee arthroplasty with a rotating hinge knee type prosthesis; uniCR: unilateral primary total knee arthroplasty with a cruciate-retaining prosthesis; bilCR: bilateral primary total knee arthroplasty with a cruciate-retaining prosthesis.

different among the groups (Figure 4). From initial contact to loading response, the tibial translation in the R-RHK, uniCR, and bilCR groups was 1.5±0.5, 1.5±2.2, and 1.1±1.4 mm, respectively, and the amount of rotation in those groups was 0.4°±1.5°, 1.2°±1.7°, and 0.5°±2.0°, respectively. Tibial translation and the amount of rotation were not significantly different among the groups (Table 4).

Discussion

The present study sought to examine kinetics and kinematics of the lower limb during gait in patients who had undergone revision TKA with RHK, and we hypothesized that the knee joint angle was smaller and the KAM was larger in the R-RHK group compared to uniCR and bilCR groups. In this study, the knee joint angles, KAM, and tibial anterior translation were not different among the R-RHK, uniCR, and bilCR groups during gait and the early stance phase, which supports our hypothesis. These findings suggest that the biomechanical data of the R-RHK group were not different compared to those of the uniCR and bilCR groups.

Gait speed in the R-RHK group was significantly lower than that in the uniCR and bilCR groups. The gait speed of patients who received primary TKA in previous studies was 0.8-1.1 m/s [9,18,19]. A decrease in gait speed is considered as an abnormal gait condition after TKA [20]. The post-surgery period in the R-RHK group tended to be longer than in the uniCR and bilCR groups (p= 0.05). This difference

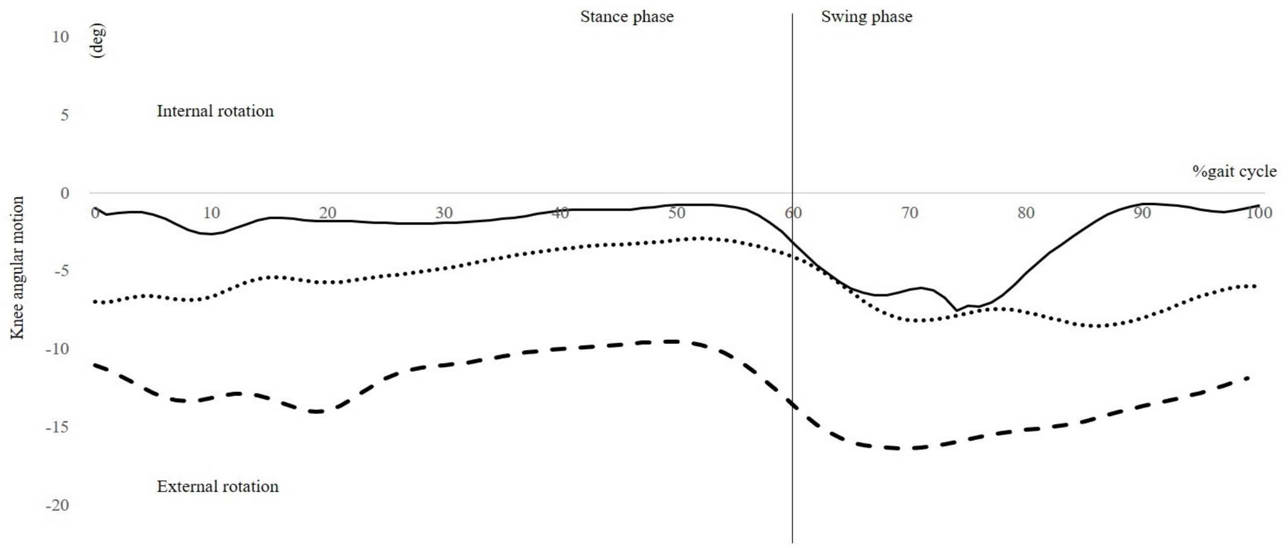

Figure 3: Knee angular motion (horizontal plane).
The continuous, dash, and dot lines represent R-RHK, uniCR, and bilCR, respectively.

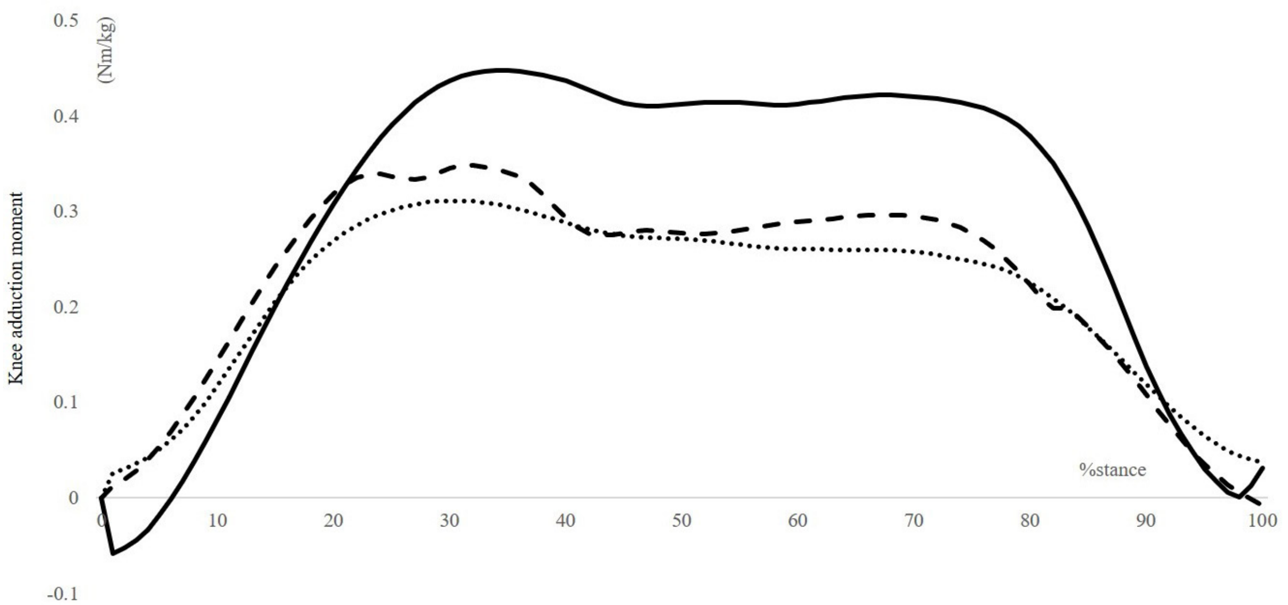

Figure 4: Knee adduction moment.
The continuous, dash, and dot lines show R-RHK, uniCR, and bilCR, respectively.
Abbreviations: R-RHK: revision total knee arthroplasty with a rotating hinge knee type prosthesis; uniCR: unilateral primary total knee arthroplasty with a cruciate-retaining prosthesis; bilCR: bilateral primary total knee arthroplasty with a cruciate-retaining prosthesis.

in the post-surgery period may have influenced the results. The results of gait speed and step length in our study suggest that R-RHK may be associated with lower gait ability compared to uniCR and bilCR.

There was no difference in the knee joint angle and moment when comparing the R-RHK group to the uniCR and bilCR groups. The maximum and minimum flexion during gait in the R-RHK group improved knee motion, which was not different from the maximum (40-60°) and minimum (0-10°) flexion that have been previously reported in primary TKA patients without RHK [18,21]. The maximum/minimum flexion angles of the knee joint during gait in the R-RHK group were not significantly different from those of primary TKA patients in previous studies. KAM was 0.2-0.6 Nm/kg in previous reports [21-23]. The KAM values of all the three groups in this study were comparable to those of previous studies [21-23]. No significant differences were found among the R-RHK, uniCR, and bilCR groups since the orthopedists controlled for the femoro-tibial angle in patients who underwent revision TKA and those who underwent primary TKA. The Western Ontario and McMaster Universities Osteoarthritis Index function score was reported to plateau at 6 months after TKA [24]. In the patients in whom revision TKA was performed because of aseptic loosening, the Knee Society Scoring System function score and clinical score were relatively good [10]. The kinetics and kinematics data of this study could be the basis for the improvement in those scores.

In our study, the amount of tibial rotation was approximately 1° in the R-RHK group from the initial contact to the loading response in the stance phase. The tibia internally rotates 4°-8° from the initial contact to the loading response in the stance phase [25-27]. The NexGen RHK prosthesis allows for tibial rotation [8]; however, our result showed lesser rotation than that in previous reports. The NexGen RHK prosthesis has a mechanism to guide the control pivot designed by a hinge and mobile bearing; thus, this motion occurs due to muscle movement and alignment.

The NexGen RHK prosthesis was developed to decrease tibial translation. Tibial translation in the R-RHK group was 1.5 mm, which was smaller than those of previous reports [2,28,29], although it was not significantly different compared to the control groups in the current study. The reason for the result of the present study is that the femoral condyle radius and bearing have a high one-to-one conformity, which enables anterior stability. In the uniCR and bilCR groups, most participants underwent CR type TKA with the anterior-stabilized (AS) bearing, which may have guided tibial rotation and translation in those groups. The AS bearing design motion may be the reason for insignificant difference in tibial rotation and translation among the three groups.

There are many studies on gait analysis in patients with TKA. However, we could not find a published gait analysis of patients with revision RHK TKA; thus, ours is the first report. The gait biomechanics in our study were similar between patients who underwent revision TKA and those who underwent primary TKA.

Limitations

Our study has some limitations. First, the patients in this study underwent revision TKA because of aseptic loosening; thus, our results may not be applicable to patients who have undergone revision surgery because of other factors. Satisfaction, pain reduction, and functional improvement were better, and complication rates were lower after revision TKA for aseptic loosening than those after revision TKA for other causes of failure [11]. Therefore, patients who have undergone revision surgery for reasons other than aseptic loosening may have lower gait ability than that of patients who have undergone revision surgery due to aseptic loosening. Second, it is unclear whether the results of this study are equally applicable to men. KOA has previously also been found to be more common in women than in men [30]. It will be necessary to analyze the kinetics and kinematics in male patients in the future. Lastly, because this study included cross-sectional data after revision TKA, the causal relationship leading to revision remains unclear.

Conclusions

The results of the present study suggest that the gait of patients who have undergone revision surgery using an RHK prosthesis for aseptic loosening TKA may have the same characteristic kinetics and kinematics as that of patients who have undergone primary TKA using another type of prosthesis. These findings can be used to guide patients in gait training in the clinical setting after revision TKA. In the future, the gait of patients who have undergone revision surgery because of other factors will be analyzed.

Conflicts of Interest

Author TY received research support from Zimmer Biomet, LLC. Other authors declare that they have no conflict of interest.

Authors' Contributions

All authors made significant contributions to the conception and design, acquisition of data, or analysis and interpretation of data. All the authors made significant contributions to drafting the manuscript or revising it critically for intellectual content.

	R-RHK	uniCR	bilCR			
	Mean± SD (95% CI)	Mean± SD (95% CI)	Mean± SD (95% CI)	F value	P-value	η^2
Tibial translation (mm)	1.46±0.52 (0.81–2.10)	1.45±2.20 (-1.29–4.18)	0.99±1.63 (-1.02–3.01)	0.01	0.99	0.00
Amount of tibial rotation angle (deg)	0.98±1.50 (-1.39–3.36)	1.69±2.51 (-2.31–5.69)	0.67±0.48 (-0.1–1.40)	1.26	0.30	0.07

Table 4: Kinetics and kinematics data from initial contact to loading response.
$p<0.05$: statistically significant difference; R-RHK: revision TKA due to aseptic loosening with the rotator hinge knee type; uniCR: unilateral primary TKA with the cruciate retaining type; bilCR: bilateral primary TKA with the cruciate retaining type; CI: confidence interval.
Tibial translation: The plus means anterior.
Rotation: The plus means internal rotation.

TO participated in the conception and design, analysis, and interpretation of data, and writing the manuscript. TY, SM, TT, RS and JK participated in the design, acquisition and interpretation of data, and revision of the manuscript. TT participated in the acquisition of data, performed the statistical analysis, and helped revise the manuscript. TT, RS and JK participated in acquisition of data, interpretation of data, and revision of the manuscript. TY and KS participated in the conception and design, analysis and interpretation of data, and drafting the manuscript as a researcher in the field of physiotherapy and orthopedics. All the authors have read and approved the final version of the manuscript.

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