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Original Article

A comparison of gait characteristics between posterior stabilized total knee and fixed bearing unicompartmental knee arthroplasties

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ABSTRACT

Background/Objective: According to previous studies, physiological gait pattern was found in unicompartmental knee arthroplasty (UKA) as compared to total knee arthroplasty (TKA) concerning the gait parameters including gait speed, cadence, and step length. However, little attention had been paid to the detailed kinematic and kinetic differences during gait between TKAs and UKAs. The aim of the present study was to investigate and to clarify the biomechanical differences between posterior stabilized TKAs and fixed bearing UKAs during walking

Methods: A total of 28 patients participated in the present study. Fifteen patients who underwent TKA and thirteen patients who underwent UKA were enrolled. Gait analysis was done at an average of 12.9 months after surgery. The subjects performed level walking at a preferred speed. For each subject, three-dimensional kinematic, kinetic and ground reaction force data were recorded as well as clinical data including range of motion at the knee joint and plain radiographs. Differences of knee kinematics or kinetics were compared between TKAs and UKAs using two-tailed Mann Whitney U-test.

Results: On physical examination, passive range motion was significantly smaller in TKAs than in UKAs, while femorotibial angle on plain radiographs was not significantly different on plain radiographs. In terms of kinematics, TKAs were more flexed at heel contact and less extended in mid-stance phase compared to UKAs in the sagittal plane, and total excursion of TKAs were also smaller than UKAs. Regarding knee kinetics, TKA patients had significantly less peak tibial internal rotation moment in terminal stance phase. In addition, peak knee adduction moment was significantly larger in UKAs than in TKAs, while peak knee flexion moment was not significantly different.

Conclusion: Posterior stabilized TKAs exhibited less peak tibial internal rotation moment, which is known as pivot shift avoidance gait, in the present study, compared to fixed bearing UKAs. TKAs had similar gait pattern to anterior cruciate ligament deficient knees, compared to UKAs even if patients with TKAs had no subjective pain during walking.

Introduction

End-stage osteoarthritis (OA) at the knee joint often deteriorates normal activities of daily living for elderly population. Clinically, symptomatic knee OA is found in approximately 14.4% of men and 28.4% of women over the age of 45.[1–4] For patients with end-stage knee OA, knee replacement surgery has traditionally been done as an effective treatment, by relieving subjective pain, ameliorating function, and remedying deformity.[5] Both total knee arthroplasty (TKA) and unicompartmental knee arthroplasty (UKA) have been used as successful treatments for end-stage knee OA or osteonecrosis (ON), although surgical indication is somewhat different between them. Proponents of UKA believe that the preservation of both cruciate ligaments, and of the remaining intact compartments of the knee, should result in more physiological knee kinematics, and hence better patient satisfaction.[6–9] On the other hand, proponents of TKA believe that lower revision rates are reported by the

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registries and no differences are found when comparing clinical outcomes between UKA and TKA.

Generally, gait analysis has been performed as clinical and functional evaluation in patients with knee replacement surgeries.[10,11] Several previous studies have indicated that the difference of kinematics and kinetics between TKAs and UKAs would be observed using gait analysis.[12–19] Recently, Nha et al. performed meta-analysis regarding the gait patterns of UKA and TKA patients during level walking by evaluating the kinetics, kinematics, and spatiotemporal parameters.[17] They evaluated several types of the implant, including posterior stabilized and posterior cruciate ligament retaining TKAs as well as fixed and mobile bearing UKAs. In their conclusion, there were no significant differences in vertical GRF, joint moment at stance, overall kinematics, walking speed, or cadence between UKA patients and TKA patients during level walking. However, the TKA group had significantly shorter stride length than UKA patients in their study. Friesenbichler et al. assessed isometric quadriceps strength, spatio-temporal gait parameters (walking speed, step length, single-limb support phase) and self-reported outcomes (pain, function, stiffness) in 18 posterior stabilized TKAs and 18 fixed bearing UKAs patients six months after surgery.[13] They concluded that UKA patients showed better short-term quadriceps strength and gait function than TKA patients, together with less self-reported pain and stiffness. However, little attention had been paid to the detailed kinematic and kinetic differences during gait between posterior stabilized TKAs and fixed bearing UKAs.

The aim of the present study was to investigate and to clarify the biomechanical differences between posterior stabilized TKAs and fixed bearing UKAs during level walking using a gait analysis system. It was hypothesized that kinematics and kinetics during gait in posterior stabilized TKAs were less physiological than in fixed bearing UKAs.

Materials and methods

Participants

A total of 28 patients participated in the present study. Fifteen patients who underwent TKA (mean age = 77.4 ± 5.1 yrs, mean body mass index = 27.1 ± 2.9 kg/m^2) and thirteen patients who underwent UKA (mean age = 72.2 ± 6.7 yrs, mean body mass index = 25.2 ± 3.2 kg/m^2) were enrolled in the present study. None of the subjects had any history of hip or ankle osteoarthritis. Twenty-one patients had medial knee OA at least grade 3 severity based on Kellgren-Lawrence grade and seven patients had ON of medial femoral condyle. All patients underwent unilateral surgeries. All TKAs were done using same measured resection technique with same implant (Trimax®, Posterior Stabilized, Ortho Development, Draper, UT, USA) and all UKAs were done using Zimmer Unicompartmental High Flex Knee® (Zimmer, Warsaw, IN, USA) by a single surgeon. The articulating polyethylene of Trimax® posterior stabilized TKA is symmetric with the standard cam-box design. Less invasive parapatellar approach was utilized as surgical exposure for TKAs and UKAs. At the time of the surgery, full extension was carefully confirmed to avoid flexion contracture for each knee. Both cruciate ligaments were sacrificed in TKAs, whereas they were preserved in UKAs. All patellae were resurfaced in TKAs, and all components were fixed with bone cement for TKAs and UKAs. Patients underwent a standard rehabilitation program which consisted of early range of motion and weight-bearing exercises as tolerated. All patients received prophylactic anticoagulants and antibiotics as necessary. Clinically, all the participants in the present study presented excellent results and could walk without subjective pain after the surgery. On physical examination, pre- and post-operative passive range of motion (ROM) was examined. On plain radiograph, pre- and post-operative femorotibial angle (FTA) was assessed. FTA evaluated using the standing radiograph of the bilateral long legs and defined as the lateral angle formed by the femur and tibia. Lines were drawn through the middle of the femoral shaft and through the middle of the tibial shaft. Thus, FTA was anatomical femorotibial angle on plain radiograph. A written informed consent form approved by Institutional Review Board of our university was obtained in each subject (#20080054).

Gait analysis

Gait analysis was done at an average of 12.9 ± 7.9 months after surgery. The subjects performed level walking at a preferred speed. Gait analysis system was consisted of 8 cameras (120 frames/s, Oqus, Qualisys, Sweden), two force plates (frequency 600 Hz; AM6110, Bertec, Columbus, OH, USA), and 46 retro-reflective markers (14 mm in diameter) (Fig. 1). Those markers were placed at the standard anatomical landmarks. Three noncollinear infrared markers were used to track each of the 8 segments: 2 feet, 2 legs, 2 thighs, pelvis, and trunk. To define the axes of each of the 8 segments, an anatomical model was created by digitizing standard bony landmarks: bilateral acromion, xiphoid process, suprasternal notch, 7th cervical vertebra, 10th thoracic vertebra, bilateral anterior and posterior superior, bilateral iliac spines, bilateral greater trochanters, bilateral lateral and medial epicondyles, bilateral lateral and medial malleoli, bilateral posterior heel, bilateral medial cuneiform, bilateral great toe, and bilateral head of the fifth metatarsal. Furthermore, additional tracking markers were placed on the frontal aspects of the thigh (4 markers) and shank (4 markers). Calibration markers (bilateral medial epicondyles and medial malleoli) were removed after the standing trial, and only

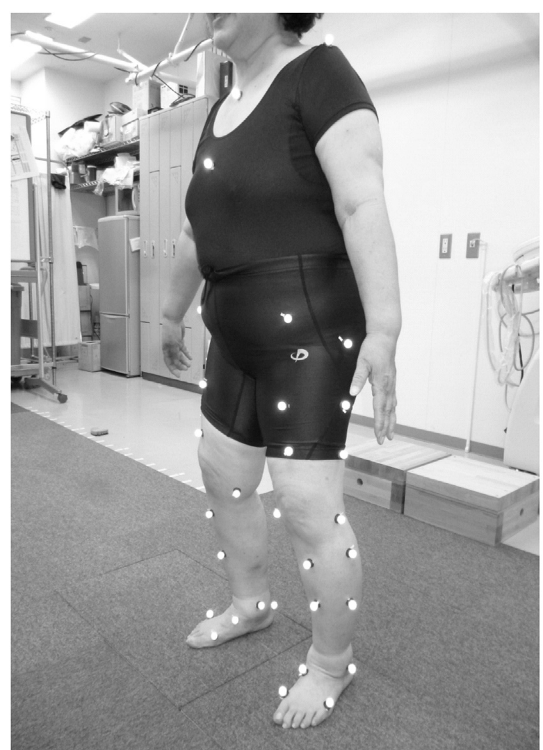

Fig. 1. A total of 46 retro-reflective markers were placed at the standard anatomical landmarks.

tracking markers were left on the subject throughout the entire data collection session. The force plate collected ground reaction force (GRF) data at 600Hz and were synchronized to the camera sampling rate (120 Hz). GRF was used to identify the time at heel contact (HC) and at toe-off (TO). For each subject, three-dimensional kinematic, kinetic and GRF data were recorded during HC to. The motion of markers was recorded by Qualisys Track Manager Software (version 2.7). To calculate knee kinematics and kinetics, Visual 3D (C-motion Company, Rockville, MD) was utilized.

Statistical analysis

As a statistical analysis, two-tailed Mann Whitney U-test was done to determine the differences of knee kinematics or kinetics between TKAs and UKAs. Categorical valuable, such as gender, was analyzed by Fisher exact probability test. P values of <0.05 were considered as significant. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., New York, USA). The sample size for the current investigation was determined to be 12 subjects in each group with 80% power. This calculation was performed using knee flexion angle at heel contact in walking, with defined significant differences of 6.0° between groups.

Results

Patients' demographics

Patients' demographics was shown in Table 1. There were no significant differences between TKAs and UKAs including age, BMI, gender, and diagnosis. However, pre- and post-operative passive range of motions, including extension limitation and flexion angles, were significantly different between them. Regarding preoperative plain radiographs, FTA(°) was 186.8 ± 5.6 in TKAs and 176.7 ± 3.6 in UKAs. TKAs had more severe varus deformity ($P < 0.001$). On the other hand, postoperative FTA (°) was 175.0 ± 2.0 in TKAs and 175.2 ± 3.0 in UKAs. No significant difference was detected in postoperative FTA. Mean follow-up interval from surgery to gait analysis was 10.7 ± 4.9 in TKAs and 15.5 ± 9.9 in UKAs. FTA and mean follow-up interval were not significantly different.

Kinematic and kinetic differences in walking

Detailed data were shown in Table 2. Different gait patterns were seen between TKAs and UKAs. Gait speed was significantly faster in UKAs than in TKAs. In terms of kinematics, TKAs were more flexed at heel contact and less extended in mid-stance phase compared to UKAs in the sagittal plane, while other kinematic parameters were not significant (Table 2 and Fig. 2). As shown in Fig. 2, total excursion of TKAs were also smaller than UKAs. Regarding knee kinetics, TKA patients had significantly less peak tibial internal rotation moment in terminal stance phase (Table 2 and Fig. 3). In addition, peak knee adduction moment was significantly larger in UKAs than in TKAs, while peak knee flexion moment was not significantly different.

Discussion

The results of the present study supported the hypothesis that kinematics and kinetics during gait in posterior stabilized TKAs were less physiological than in fixed bearing UKAs. The most important finding of the current investigation was that posterior stabilized TKA patients had significantly less peak tibial internal rotation moment in terminal stance phase, compared to fixed bearing UKAs. This phenomenon during gait is known as the anterior cruciate ligament (ACL) deficient pattern. Specifically, this pattern is known as pivot-shift avoidance gait which is gait characteristics of patients with ACL deficient knees.[20] In addition, more flexed at heel contact and less extended in mid-stance phase in TKAs in the sagittal plane were observed. These abnormal movement are well known as stiffening strategy which is gait characteristics of patients with ACL deficient knees.[21] However, this phenomenon in the present study was possibly related to smaller range of motion (excursion) during gait in TKAs.

Several previous studies have indicated that the difference of kinematics and kinetics between TKAs and UKAs would be observed using gait analysis. Jung et al. investigated the difference during stair walking in patients with simultaneous TKA and UKA, and concluded that UKA knee might allow greater degree of rotation freedom, which resembled normal knee kinematics during stair walking.[22] In particular, UKA knees exhibited significantly greater degree of rotation in transverse planes, compared to TKA. However, in their study, peak tibial internal rotation moment in terminal stance phase was not evaluated. Moreover, Jones et al. evaluated the difference of gait characteristics between 12 patients with cruciate-retaining TKA and 12 with mobile-bearing medial UKA.[14] They suggested that top walking speed in TKA patients was significantly lower than that of UKA group, and concluded that UKA would result in a more physiological gait compared with TKA. Generally, posterior stabilized TKAs need ACL excision as well as posterior cruciate ligament during the surgery, which leads to ACL deficient knees, whilst UKAs preserve ACL. Thus, previous gait analysis comparing TKA with healthy controls consistently report loss of the normal biphasic flexion/extension moments around the knee, with associated quadriceps avoidance gait.[9] This phenomenon is observed much less frequently in UKA based on previous

Table 1
Patient data in each group (Mean ± SD).

Patient data	TKA (N = 15)	UKA (N = 13)	P Value[a]
Age (yrs)	77.4 ± 5.1	72.2 ± 6.7	0.06
BMI (kg/m^2)	27.1 ± 2.9	25.2 ± 3.2	0.11
Gender (Female/Male)	15/0	11/2	0.21
Diagnosis (OA/ON)	13/2	8/5	0.27
Preoperative ROM (Extension imitation) (°)	9.6 ± 4.8	3.4 ± 3.9	0.003
Preoperative ROM (Flexion) (°)	114.3 ± 10.3	136.4 ± 6.7	< 0.001
Preoperative FTA (°)	186.8 ± 5.6	176.7 ± 3.6	< 0.001
Postoperative ROM (Extension imitation) (°)	4.3 ± 3.1	1.5 ± 3.6	0.02
Postoperative ROM (Flexion) (°)	116.7 ± 12.2	134.2 ± 5.5	<0.001
Postoperative FTA (°)	175.0 ± 2.0	175.2 ± 3.0	0.80
Follow-up interval (months)	10.7 ± 4.9	15.5 ± 9.9	0.11

[a] Values obtained using Mann Whitney U-test or Fisher's exact probability test.

Table 2
Kinematic and kinetic data in walking (mean ± SD).

Biomechanical data	TKA	UKA	P Value[a]
Gait speed (m/s)	0.85 ± 0.20	1.06 ± 0.18	0.011
Knee flexion angle at heel contact (°)	10.6 ± 4.6	3.8 ± 4.8	<0.01
Knee flexion angle during mid-stance phase (°)	8.2 ± 5.1	1.3 ± 6.4	0.018
Peak knee adduction angle during stance phase (°)	0.5 ± 3.0	1.5 ± 4.8	0.70
Peak knee internal rotation angle in walking (°)	7.2 ± 4.9	7.8 ± 5.5	0.63
Peak knee flexion moment in walking (Nm/kg)	0.35 ± 0.20	0.34 ± 0.21	0.77
Peak knee adduction moment in walking (Nm/kg)	0.44 ± 0.15	0.56 ± 0.15	0.029
Peak tibial internal rotation moment in walking (Nm/kg)	0.06 ± 0.04	0.15 ± 0.06	<0.001

[a] Values obtained using Mann Whitney U-test.

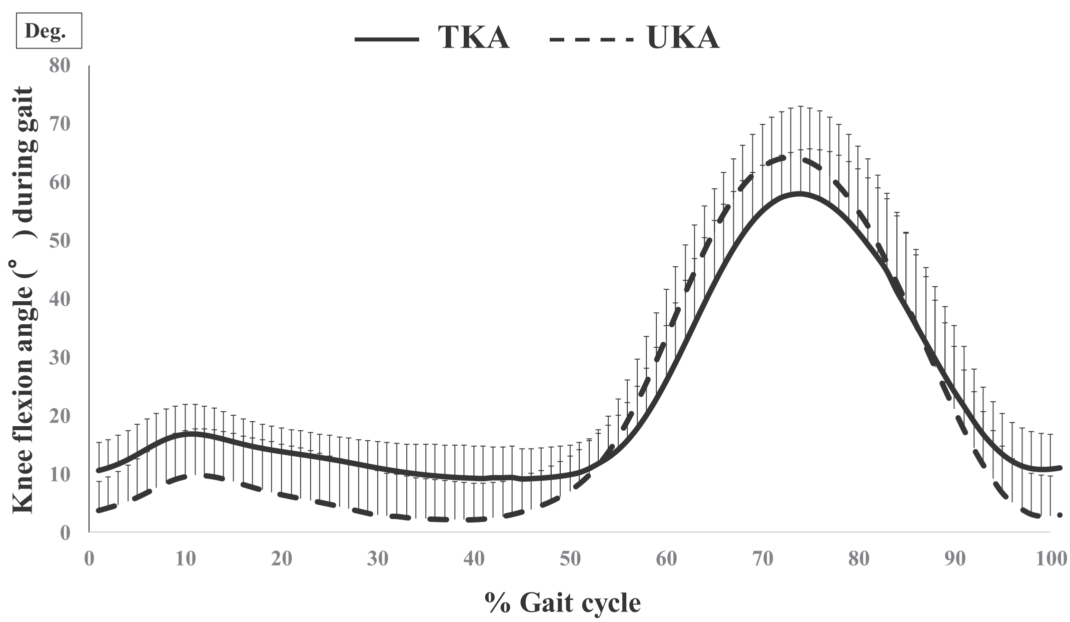

Fig. 2. Kinematic waveform in the sagittal plane. Knee flexion angles at heel contact and during weight acceptance phase were larger in TKA patients, compared with UKA patients.

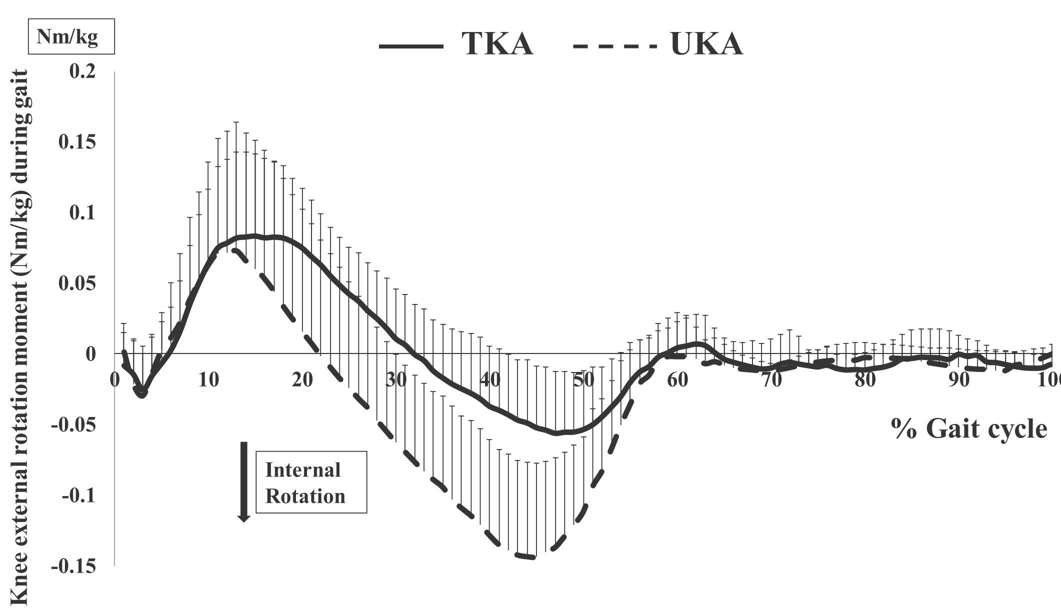

Fig. 3. Kinetic waveform in the axial plane. Internal rotation moment was smaller in TKA patients, compared with UKA patients.

study.[6] In the present study, although peak knee flexion moment in walking was not significantly different, ACL deficient pattern was observed only in TKAs, as stiffening strategy and pivot-shift avoidance pattern were detected. In addition, external knee adduction moment was significantly larger in UKAs than in TKAs. Presumably, this was related to the difference of gait speed, as FTA on plain radiographs was not significantly different. Large knee adduction moment may lead to postoperative loosening in UKAs, compared to TKAs.

Several limitations should be noted in the present study. First, preoperative gait analysis was not done for each patient. Thus, preoperative gait function which might affect postoperative gait characteristics was unknown. Second, even if age was not significantly different, patients in UKAs were relatively young. This fact could affect gait function. Third, gait speed was significantly faster in UKAs than in TKAs. Gait speed was known as the important factor affecting gait parameters including kinematics and kinetics. Therefore, the difference of peak values of knee adduction and tibial internal rotation moments might be affected by walking speed, although the patterns of kinematic and kinetic wave form were less affected. Forth, contralateral knee was not assessed. Extension deficit of the contralateral knee might lead to gait adaptation. Lastly, the degenerative change of the spine was not evaluated. As decrease of lumber lordosis was related to extension deficit of the knee joint during walking, degenerative change of the lumbar spine was possibly important. However, the results of the current study provide valuable information when considering the biomechanical differences between TKAs and UKAs during walking.

Conclusion

Posterior stabilized TKAs exhibited pivot shift avoidance gait in the present study, compared to fixed bearing UKAs. The conclusion of the present study was that TKAs had similar gait pattern to ACL deficient knees, compared to UKAs even if patients had no subjective pain during walking.

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CRediT authorship contribution statement

Kohei Nishizawa: Funding acquisition, Data curation, Writing - original draft, names . **Kengo Harato:** Conceptualization, Conception and design of study, Formal analysis, analysis and/or interpretation of, Data curation, data, Writing - original draft, Drafting the manuscript, Approval of the version of the manuscript to be published (the names of all authors must be listed). **Yutaro Morishige:** Funding acquisition, acquisition of, Data curation, data, Approval of the version of the manuscript to be published (the names of all authors must be listed). **Shu Kobayashi:** Conceptualization, Conception and design of study, Funding acquisition, acquisition of, Data curation, data, Formal analysis, analysis and/or interpretation of data, Approval of the version of the manuscript to be published (the names of all authors must be listed). **Yasuo Niki:** revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published (the names of all authors must be listed). **Takeo Nagura:** Formal analysis, analysis and/or interpretation of, Data curation, data, revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published (the names of all authors must be listed).

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asmart.2020.07.003.

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