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Research Article

Gait Oscillation Analysis during Gait and Stair Stepping in Two Total Knee Replacement Designs

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Abstract

Background: The analysis of gait oscillation is necessary to assess gait abnormality after total knee arthroplasty. The goal of this analysis was to assess the influence of different posterior stabilized implant designs on gait oscillation during gait and stair stepping in patients after TKA.

Methods: Twenty-six patients that underwent unilateral TKA with Bi-surface KU5 (unique PS) and Actiyas posterior stabilizing (PS) were assessed. Acceleration (anterior, TKA side and contralateral side direction) and gait barycentric factors (single-support phase and ratio of the center of gravity maximum values) between gait and stair stepping were measured.

Result: Acceleration to the contralateral side in the sacral and dorsal vertebral region increased at stair-up more after the PS group than after the unique PS group. The single-support phase was close to 1 during gait and stair stepping after the unique PS group. On the other hand, the single-support phase was close to 1 during gait but was not close to 1 during stair stepping after the PS group.

Conclusion: We considered that stair-down might be performed mainly on the pelvic girdle slightly more in the PS group than in the unique PS group, and that gait oscillation during stair-stepping might remain slightly more in the PS group than in the unique PS group.

Keywords: *Gait Analysis; Total Knee Arthroplasty; Osteoarthritis of the Knee*

Introduction

Total knee arthroplasty (TKA) has achieved successful clinical outcomes in patients with knee osteoarthritis (OA). Many knee implants have been designed. The main designs of knee prosthesis are mobile and fixed bearing TKA. In fixed bearing TKA, cruciate-retaining (CR) TKA and posterior-stabilizing (PS) TKA have been designed. Knee implants can partially replace the function of lost structures. Many knees showed significantly different kinematics between the gait and stair activities, as well as differences from knee with other implant designs [1]. The implant design may influence the function of the knee after TKA. The Bi-surface PS (Kyocera Medical Corporation, Japan) has a characteristic structure compared to the other PS [2,3]. We reported on gait oscillation during gait and stair stepping in patients after total knee arthroplasty with Bi-surface PS. The influence of difference of PS implant designs on gait oscillation during walking in patients after TKA might occur [4].

Purpose of the Study

The purpose of this study was to investigate how the different PS implant designs affect gait oscillation during gait and stair stepping in patients after TKA and to assess which implant type is closer to normal walking.

Materials and Methods

Thirteen patients who underwent TKA with Actiyas Posterior stabilizing prosthesis (Kyocera Medical Corporation, Japan) [5] participated in this study. Thirteen patients who underwent TKA with the Bi-surface KU5 knee prosthesis were extracted from the data previously enforced [4]. There were 22 female patients and 4 male patients with an average age of 75.1 (range: 63 - 87) years. The diagnosis was osteoarthritis. All of the patients were followed-up for more than one year before being assessed (Table 1). All patient had undergone the parapatellar approach, which were performed by one surgeon. The patella was not resurfaced. All components were fixed with cement.

	KU5	Actiyas
Mean age	75.4 ± 7.3	74.8 ± 6.1
Gender (male/female)	3/10	2/11
Mean body mass index	22.4 ± 3.1	25.1 ± 4.6
Diagnosis (OA)	13	13
HSS score	94.1 ± 3.3	94.4 ± 2.6
Mean follow-up (months)	38.6 ± 7.6	16.5 ± 2.6

Table 1: *Patient characteristics.*

At the time of the study, patients were 27.6 (range: 13 - 48) months postoperative. The mean postoperative knee-rating scale of the Hospital for Special Surgery score was 94.1 and 94.3 for the Bi-surface KU5 knee prosthesis (unique PS) group and Actiyas Posterior stabilizing prosthesis (PS) group, respectively.

Acceleration (anterior, TKA side and contralateral side direction) and gait barycentric factors (single-support phase and ratio of the center of gravity maximum values) between gait and stair stepping were measured [4,6]. These results between the unique PS group and the PS group were compared using one-factor repeated measures analysis of variance. As a control of normal gait, comparison was made with the previously evaluated healthy adult group [6]. Statistical analysis was performed using R2.8.1. The Shaffer method was used for the multiple comparison procedure [7].

Using a 2-point gait oscillometer MVP-WS2-S (Microstone Corp., Japan), we assessed gait oscillation during gait (10m) and stair-stepping [4,6]. Three successful measurements were recorded, and the recordings were used for the analysis.

Results

Acceleration

To the anterior direction

There was a significant difference between the unique PS group and the healthy adult group in acceleration in the anterior direction during gait and stair-down in the sacral region ($p < 0.05$). There was a significant difference between the both PS group and the healthy adult group in acceleration in the anterior direction during gait ($p < 0.05$) and stair-stepping ($p < 0.01$) in the dorsal vertebral region. There was a significant difference in stair-down in the sacral region between the unique PS group and the PS group ($p < 0.05$).

There was no significant difference in gait and stair-up in the dorsal vertebral region and the sacral region between the unique PS group and the PS group.

To the TKA side direction

There was a significant difference between the PS group and the healthy adult group in acceleration in the TKA side direction during gait in the sacral region ($p < 0.05$). There was no significant difference in gait and stair-stepping in the dorsal vertebral region and the sacral region between the unique PS group and the PS group.

To the contralateral side direction

There was a significant difference between the PS group and the healthy adult group in acceleration in the contralateral side direction during stair-up in the sacral region ($p < 0.05$). There was a significant difference between the unique PS group and the healthy adult group in acceleration in the contralateral side direction during stair-up in the dorsal vertebral region ($p < 0.05$). There was a significant difference between the both PS type and the healthy adult group in acceleration in the contralateral side direction during gait in the dorsal vertebral region ($p < 0.01$). There was a significant difference in stair-up in the dorsal vertebral regions the sacral region between the unique PS group and the PS group.

There was no significant difference in gait and stair-down in the sacral region and dorsal vertebral regions between the unique PS group and the PS group.

Single-support phase

There was no significant difference in single-support phase during the gait values between the both PS group and the healthy adult group. There was a significant difference between both PS group and the healthy adult group in single-support time during gait and stair-stepping values. The single-support phase in the PS group was close to 1 for gait and stair-stepping. The single-support phase in the unique PS group was longer for stair-stepping than for gait. The single-support time was longer for stair-stepping than for gait in the unique PS group and the PS group.

Ratio of the center of gravity maximum values

There was a significant difference between the both PS group and the healthy adult group during stair-up in the sacral region ($p < 0.01$). There was a significant difference between the PS group and the healthy adult group during stair-up in the dorsal vertebral region ($p < 0.05$). The ratio of the center of gravity maximum values in the unique PS group and the PS group was greater for the sacral region than for the dorsal vertebral region in gait and stair-stepping. There was no significant difference in the gait and stair-stepping values between the unique PS group and the PS group (Table 2).

	Gait			Step-up			Step-down			
	Unique PS	PS	Healthy adult	Unique PS	PS	Healthy adult	Unique PS	PS	Healthy adult	
Acceleration										
To the anterior										
Sacral region	6.63 ± 2.72	7.24 ± 4.16	8.19 ± 1.91	8.31 ± 3.09	8.08 ± 3.47	7.14 ± 2.42	5.78 ± 3.00	8.43 ± 3.47	7.62 ± 1.88	Gait, down; Healthy > UPS*, down; PS > UPS*
Dorsal vertebral region	6.25 ± 1.12	6.16 ± 1.68	4.97 ± 1.56	7.27 ± 2.04	7.39 ± 2.50	4.65 ± 1.21	5.95 ± 2.59	7.27 ± 3.25	3.81 ± 1.40	Gait*, stair stepping**; Healthy<PS, UPS,
To the TKA direction										
Sacral region	4.67 ± 1.31	4.78 ± 1.97	5.88 ± 1.92	4.20 ± 1.44	4.38 ± 1.67	4.35 ± 1.72	5.61 ± 2.88	7.38 ± 3.76	5.54 ± 2.61	Gait; Healthy > UPS*,
Dorsal vertebral region	3.80 ± 1.38	3.40 ± 1.82	3.71 ± 1.02	2.79 ± 0.75	2.54 ± 1.26	3.14 ± 1.02	4.71 ± 2.13	4.69 ± 2.60	3.92 ± 1.82	Gait, down; Healthy > UPS*
To the contralateral direction										

Sacral region	4.94 ± 2.10	4.87 ± 3.51	5.86 ± 2.21	4.17 ± 1.58	2.79 ± 1.28	4.33 ± 1.72	6.21 ± 2.25	6.96 ± 3.79	5.24 ± 2.73	Gait, down; Healthy > UPS* up; Healthy > PS* PS < UPS*
Dorsal vertebral region	3.61 ± 0.95	3.11 ± 1.02	3.20 ± 1.33	3.00 ± 0.80	2.09 ± 1.28	2.45 ± 0.89	3.98 ± 1.27	4.13 ± 2.08	2.88 ± 1.38	Up; Healthy < UPS* down; Healthy < UPS, PS* up; PS < UPS*
Single-support time										
TKA side	0.54 ± 0.07	0.54 ± 0.06	0.52 ± 0.05	0.65 ± 0.10	0.76 ± 0.38	0.57 ± 0.06	0.76 ± 0.18	0.90 ± 0.48	0.55 ± 0.05	Stair stepping**; Healthy < PS, UPS
Contralateral side	0.53 ± 0.08	0.52 ± 0.06	0.53 ± 0.05	0.64 ± 0.09	0.69 ± 0.15	0.58 ± 0.06	0.71 ± 0.14	0.77 ± 0.32	0.55 ± 0.07	Stair stepping**; Healthy < PS, UPS
Single-support phase	1.03 ± 0.16	1.04 ± 0.13	0.99 ± 0.09	1.00 ± 0.06	1.20 ± 0.87	0.99 ± 0.06	1.05 ± 0.11	1.37 ± 1.33	0.99 ± 0.10	
Ratio of the center of gravity maximum values										
Sacral region	0.81 ± 0.48	0.86 ± 0.38	0.76 ± 0.30	0.82 ± 0.48	0.79 ± 0.36	0.75 ± 0.32	0.76 ± 0.30	0.78 ± 0.42	0.80 ± 0.32	
Dorsal vertebral region	0.64 ± 0.54	0.64 ± 0.24	0.64 ± 0.24	0.66 ± 0.26	0.70 ± 0.34	0.40 ± 0.15	0.55 ± 0.31	0.62 ± 0.53	0.39 ± 0.17	Up**; Healthy < PS, UPS, down*; Healthy < PS

Table 2: **p < 0.05; **p < 0.01.*

Discussion

There have been numerous studies of total knee arthroplasty performance during daily life. Banks reported that superior performance was associated with devices that provide the greatest intrinsic control of knee motions. Intrinsically stable knees may offer a significant benefit for both patient function and wear reduction [1]. Many knees showed significantly different kinematics between gait and stair-climbing activities, as well as differences from knees with other implant designs [2,8-12]. Knee and lower limb kinematics, kinetics, and electromyography have been reported for total knee arthroplasty using gait analysis [7,9,13-15]. Important kinematic and kinetic differences between CR and PS patients were observed in stair ascent [3,8,11,16]. Andriacchi reported that more stressful stair ascent motor tasks clearly differentiated function among different prosthesis designs [17]. On the other hand, Bolanos reported no differences between CR and PS designs during level walking and stair ascent [9]. By combining gait and fluoroscopic analysis, Fantozzi reported a significant correlation between knee flexion at foot strike and the position of the mid-condylar contact points, and between the maximum knee adduction moment and the corresponding lateral trunk tilt [18]. Previously, we reported on assessment of gait oscillation with a 2-point gait oscillometer in the cases of OA that received only unilateral TKA with the unique PS group. Gait oscillation was smaller at the dorsal vertebral region than at the sacral region. In comparison with the contralateral side, the load is equal on the TKA side during walking and stair stepping. This is more obvious during stair stepping than walking [4]. In this study, we examined the difference of gait oscillation between two different prosthesis designs. Acceleration in the anterior direction in the sacral region during gait and stair-stepping was greater in healthy adult group than in both PS group. The ratio of the center of gravity maximum values was greater for the sacral region than for the dorsal vertebral region. This is more obvious in healthy adult group than in both PS group. From these findings, we considered that gait and stair-stepping might be performed mainly on the pelvic girdle more in healthy adult group than in both PS group [6]. The ratio of the center of gravity maximum values in the dorsal vertebral region during stair-stepping was greater in both PS group than in healthy adult group. Therefore, we considered that TKA patients might compensate for stair-stepping motion with anteroposterior movement of the upper trunk, and gait oscillation in the anterior direction during stair-stepping might remain in TKA patients [17]. In the influence of difference of PS implant designs, acceleration to the anterior direction in the sacral region was increased during stair-down more after the PS group than after the unique PS group. We considered that stair-down might be performed mainly on the pelvic girdle slightly more in the PS group than in the unique PS group. Acceleration to contralateral direction in the dorsal vertebral regions increased during stair-stepping more in the both PS group than the healthy adult group. The ratio of the center of gravity maximum values in the dorsal vertebral region during stair-stepping was greater in both PS group than in healthy adults. We considered that gait oscillation in the lateral direction during stair-stepping might remain in both PS group. Acceleration to contralateral direction in the dorsal vertebral regions increased during stair-up more after the PS group than after the unique PS group. The single-support phase was close to 1 at gait and stair stepping after the unique PS group. On the other hand, the single-support phase was close to 1 at gait, but it was not close to 1 at stair stepping after the PS group. In the influence of difference of PS implant designs, we considered that gait oscillation during stair-stepping might remain slightly more in the PS group than in the unique PS group.

Limitation of the Study

There were some limitations in our study. The small number of patients weakens the statistical power of the results. The mean follow-up time between both groups is different. Further investigation with a larger sample size is needed to obtain more clinical data. In addition, no control group and standard error of measurements may have decreased the generalization power of this study. Despite all these limitations, the present study contributes significantly to the improvement of knee prosthesis designs.

Conclusion

We considered that stair-down might be performed mainly on the pelvic girdle slightly more in the PS group than in the unique PS group, and that gait oscillation during stair-stepping might remain slightly more in the PS group than in the unique PS group.

Ethics Approval and Consent to Participate

This study was approved by Ethical Review Boards of Kanmon Medical Center (Shimonoseki, Japan). Informed consent to participate in our study was obtained from participants.

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Availability of Data and Materials

The authors are unable to share raw data because ethical approval was not obtained for data sharing. In addition, informed consent for data sharing was not obtained from the individuals. Please find all summarized datasets reported in the results section and the tables.

Consent for Publication

We have obtained consent to publish from the participants.

Competing Interests

The authors declare that they have no competing interests.

Author's Contributions

TM designed the study, analyzed the data, and wrote the manuscript. MK, JS, YF, KI, HK, RK and RD collected the data and participated in the design of the study. MK, JS and YF analyzed the data, and helped write. All authors have read and approved the final manuscript.

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