

Quantitative gait analysis of patients with bilateral hip osteoarthritis excluding the influence of walking speed

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Quantitative gait analysis of patients with bilateral hip osteoarthritis excluding the influence of walking speed

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Running title: Gait analysis in bilateral hip osteoarthritis

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ABSTRACT

Background: The purpose of this study was to investigate gait characteristics of patients with bilateral hip osteoarthritis (BHO), independent of walking speed.

25 **Methods:** We measured gait parameters in twelve BHO patients during free walking activities, and in twelve normal adults during both free walking and slow walking activities using a three-dimensional computerized gait analysis system.

Results: Patients with BHO had a lower walking speed, step length, and cadence than normal subjects during free walking. When compared with normal subjects
30 walking at a slow speed, the walking speed difference among BHO patients disappeared, although BHO patients retained a relatively high cadence. Kinematic and kinetic factor analysis of BHO patients at free speed compared to normal subjects walking at a slow speed showed a forward-tilted pelvic angle in the BHO patients that also dropped to the ipsilateral side in the stance phase. The peak
35 extension and abduction angle of the hip, the peak abduction moment of the hip were all low, while the peak generation power of the ankle was high in BHO patients.

Conclusions: Gait characteristics of patients with BHO, independent of walking speed, were 1) increased cadence and ankle generation power, 2) reduced step width,
40 hip extension and abduction angle, as well as a lower hip abduction moment, 3) maintained forward tilting of the pelvis during gait cycle, and 4) appearance of a dropped pelvis in the stance phase.

Introduction

45 Gait pattern analysis in patients with hip joint disease is important for assessing physiological deterioration. In particular, several authors have stressed the importance of physical therapy for patients with osteoarthritis of the hip joint.¹⁻³ Physical therapy in such cases should aim to restore or maintain optimal gait patterns that are as close to normal as possible, to maximize the walking efficiency and quality of life in these patients. To our knowledge, only one study has thus far proposed a strategy to achieve this goal in patients with early-stage unilateral hip osteoarthritis.⁴

Gait characteristics of patients with hip osteoarthritis are commonly measured using the three-dimensional gait analysis system.⁴⁻¹⁵ The patients assessed by this method predominantly suffered from unilateral hip osteoarthritis,⁴⁻⁹ and a limited number of patients with mixed unilateral and bilateral hip osteoarthritis (BHO) were examined.¹⁰ However, studies on the gait characteristics of patients with bilateral hip osteoarthritis are scarce.^{11, 16} Impaired hip function in unilateral hip osteoarthritis patients can be compensated by an increase in pelvic motion and muscle power generation or absorption modifications in other joints of contralateral leg during walking.⁴⁻⁹ However, kinematic and kinetic influences of the other joints of ipsilateral leg and pelvis would be greater in BHO patients, who cannot compensate by the contralateral leg joint.

Many gait variables have been correlated with walking speed, with most
65 decreasing with reduction in walking speed in normal subjects¹⁷⁻²¹ and in patients
with unilateral hip osteoarthritis.⁵ It is therefore difficult to compare gait
characteristics between normal subjects and BHO patients using self-determined
speeds, due to the difficulty in determining whether the gait characteristics of BHO
patients were causal of the disease or had an indirect effect via the affected walking
70 speed of the patient. Recent gait analysis studies of patients have excluded the
influence of walking speed,^{5, 19-25} to allow comparison of different patients walking at
self-determined speeds.¹

The aim of the present study was to determine the gait characteristics of BHO
patients independent of walking speed.

Materials and Methods

Subjects

Symptomatic BHO patients, comprising 12 women aged 59.4 ± 11.1 years (mean \pm
80 SD), with a mean height of 150.6 ± 6.1 cm, mean weight of 56.7 ± 7.1 kg and mean
Body Mass Index (BMI) of 24.9 ± 3.4 kg/m², were entered into the study. The
severity of osteoarthritis was assessed using the Kellgren & Lawrence²⁶ scale, and all
patients were categorized as grade III-IV. They had no neurological or
cardiopulmonary problems. The average Japanese Orthopaedic Association (JOA)
85 hip score²⁷ of patients was 53.9 ± 15.9 points. All patients did not display a

limb-length discrepancy larger than 2cm. Eight hips had a Duchenne sign, and sixteen hips had a Trendelenburg's sign. All patients were seriously limited in their activities due to severe pain. The normal control subjects were 12 healthy women aged 64.3 ± 2.8 years, with a mean height of 148.1 ± 5.1 cm, mean weight of 52.5 ± 7.8 kg, and mean BMI of 23.9 ± 2.8 kg/m². Mean age, mean height, mean weight, and mean BMI had no significant differences between BHO patients and normal subjects. The University Research Ethics Board approved the study and all subjects provided written informed consent.

Data Collection and Testing Procedures

Gait was analyzed using the VICON 370 system (Vicon Peak Ltd., Unit 14, West Way, Oxford OX2 0JB, England), which has six strobe cameras (Vicon Peak Ltd., Unit 14, West Way, Oxford OX2 0JB, England) to cover the area required for the complete gait cycle and four force plates (Advanced Mechanical Technology Inc., 176 Waltham Street, Watertown, MA 02172, USA) located in the middle of a 10-meter walkway. Before data collection, all cameras were calibrated, and the sampling rate was set at 60 Hz.

Fifteen reflective markers were placed over anatomic landmarks of the sacrum, anterior superior iliac spine, middle thigh, knee, middle leg, ankle, heel, and toe of each lower limb according to the VICON Clinical Manager (VCM) protocol^a. Video data of each subject were obtained while the subject was standing in an upright position to establish the neutral position of the joints and lower limb

segments. Afterward, subjects were asked to walk barefoot along a 10-meter laboratory walkway at varying speeds (Fig. 1). The BHO patients walked at a free speed, while the normal subjects walked at both a free speed and slow speed. When the normal subjects walked at a slow speed, they were just asked to “walk slowly”. After a few practice trials, we recorded three trials for each condition.

Gait variables were normalized to percent gait cycle. Each cycle began and ended with the initial contact of each foot. After normalization, the average percent gait cycles of bilateral legs were collected. The temporal and distance gait parameters consisted of walking speed, single-limb stance rate, step length, and cadence; these were analyzed using VCM software. Step width was calculated from the distance between the right and left ankle joint centers at the initial contact of each foot. Moreover, the step length and step width were normalized to patient height and reported as a percentage. All kinematic and kinetic factors were also calculated using VCM software. The kinematic factors consisted of the pelvic, hip, knee and ankle joint in the sagittal and frontal planes. Pelvic obliquity, which was the movement of the pelvis in the frontal plane, had a positive angle value when the pelvis dropped to the contralateral side and a negative angle value when the pelvis dropped to the ipsilateral side.¹² The kinetic factors consisted of joint moment and joint power of the hip, knee and ankle in the sagittal and frontal planes, which were normalized for body weight, and which were described as newton-meters per kilogram and watts per kilogram. When the joint moments and the angular velocities had the same polarity, the power was positive and was considered to

130 generate energy during a concentric muscle contraction. When the polarities were
different, the power was negative and it was assumed that energy was absorbed in
an eccentric muscle contraction.⁴ The trajectory peak values were selected
according to a previous study^{4, 28} and the averages of these values were compared
between groups.

135 *Statistical Analysis*

Statistical evaluation was performed using one-way analysis of variance (ANOVA)
for the temporal and distance factors to compare BHO patients and normal subjects
walking at a free speed, as well as normal subjects walking at a slow speed. The
140 Bonferoni test was used for post-hoc analysis. The unpaired t-test was used to
compare kinematic and kinetic factors between BHO patients and normal subjects
when they walked at a slow speed. Statistically significant differences were defined
as $p < 0.05$.

145 **Results**

Temporal and Walking Distance Parameters

Figure 2 and table 1 show the temporal and distance factors for BHO patients and
normal subjects. The BHO patients walked significantly slower than normal
150 subjects walking at a free speed (0.65 ± 0.16 versus 1.12 ± 0.15 m/s), but no significant
differences were noted between the BHO patients at free speed and the normal

subjects walking at a slow speed (0.65 ± 0.16 versus 0.61 ± 0.14 m/s, $p < 0.05$). The BHO patients walked with significantly shorter step length (26.06 ± 3.21 versus 36.94 ± 2.42 or 32.11 ± 3.86 %, $p < 0.05$) and width (7.25 ± 1.65 versus 9.21 ± 1.96 or 10.13 ± 2.08 %, $p < 0.05$) compared to normal subjects walking at either free or slow speed. The BHO patients walked with lower cadence than normal subjects walking at a free speed (99.31 ± 18.11 versus 120.47 ± 9.95 steps/min, $p < 0.05$) but higher than the normal subjects walking at a slow speed (99.31 ± 18.11 versus 75.98 ± 12.58 steps/min). There were no significant differences in single limb stance rate among BHO patients (41.02 ± 12.64 %) and normal subjects in the two conditions (47.26 ± 5.62 or 46.79 ± 6.48 %).

Kinematic Factors

Figure 3 and table 2 show the joint angle trajectories in the sagittal and frontal plane.

The pelvic angle in the BHO patients remained forward-tilting compared with normal subjects walking at a slow speed during the gait cycle (19.01 ± 5.28 versus 10.99 ± 4.90 degree). And the pelvis in the normal subjects walking at a slow speed dropped to the contralateral side in the stance phase. In contrast, the pelvis in the BHO patients dropped to the ipsilateral side. The peak extension angle of the hip in BHO patients was significantly lower than normal subjects walking at a slow speed (3.93 ± 6.61 versus -10.18 ± 6.68 degree). The peak hip abduction angle in the BHO patients was significantly lower than in normal subjects walking at a slow speed (1.96 ± 2.66 versus -3.17 ± 3.16 degree). The knee and ankle peak angles in the

BHO patients showed no significant differences compared with normal subjects

175 walking at a slow speed.

Kinetic Factors

Figure 4 and table 2 shows the joint moment and power trajectories in the sagittal and frontal plane. The peak abduction moment of the hip in the BHO patients was significantly lower than normal subjects walking at a slow speed (0.68 ± 0.14 versus 0.83 ± 0.10 Nm/kg). The BHO patients had a higher peak generation power of the ankle than normal subjects walking at a slow speed (1.82 ± 0.63 versus 1.35 ± 0.43 Watts/kg). There were no significant differences in the other moment and power peaks.

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Discussion

Several reports have described gait characteristics in patients with unilateral hip osteoarthritis,⁴⁻¹⁶ however, the gait patterns of BHO patients may deviate from those with unilateral hip osteoarthritis. Tanaka¹¹ from our laboratory characterized the gait patterns of BHO patients as follows: reduced gait speed, cadence, step length, single stance phase, joint angular excursions, and joint moment excursions. However, the above study did not exclude the effect of walking speed.

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195 A previous study that tried to exclude the influence of walking speed
involved the control of the walking speed by using a treadmill.^{5, 14, 22} However, the
use of a treadmill might affect the floor gait characteristics.²⁹ Other methods
compensated for walking speed when measuring different gait variables using
regression equations,^{19, 20, 24, 25} or by requesting that normal subjects walk as slowly as
200 the patients.²³ Compensation for walking speed may be useful, but Möckel et al.⁵
concluded that this was a complex method. Enforcement of controlled walking
speed in normal subjects may be one of the most appropriate methods to exclude the
influence of walking speed, although Messier et al.²³ concluded that this was a
time-consuming procedure. We therefore selected slow walking speeds for normal
205 subjects to compare the gait variables with BHO patients. In our results, BHO
patients walked at a similar pace to the normal subjects walking at a slow speed. It
is well-known that cadence and step length have fixed ratio uninvolved with
decrease of walking speed in normal subjects. Some disease would change this
ratio.³⁰ We matched walking speed between that of BHO patients and normal
210 subjects. However, theoretically, consistency of each of cadence and step length is
ideal, but there is difficulty because BHO patients may change their intrinsic walking
pattern after the compensation procedure. Consequently, we could compare
kinematic and kinetic factors between BHO patients walking at a free speed and
normal subjects walking at a slow speed to exclude the walking-speed factor.

215 In our study, many variables in BHO patients were lower than those in
normal subjects walking at a free speed. These results were in approximate

agreement with the results of Tanaka¹¹; however, the gait variables of BHO patients assessed without the influence of walking speed manifested as increased cadence, narrowed step width, maintained forward tilting of the pelvis, dropped pelvis on the stance side, reduced hip extension and abduction angle, reduced hip abduction moment, and increased ankle generation power. It appears that the hip extension movement is particularly important in maintaining walking speed. Loss of bilateral hip extension movements led to maintained forward tilting of the pelvis, resulting in excessive lumbar lordosis. There were no significant differences on knee and ankle angle between BHO patients and normal subjects walking at a slow speed, in this study, but ankle plantarflexion angle in the terminal stance phase tended decrease (fig. 3). Decreasing of ankle plantarflexion angle and increasing of ankle generation power allow BHO patients to compensate a loss of hip extension movement. We suggest that ankle joint could compensate impaired hip motion, but knee joint could not.

According to Watelain⁴, subjects with a painful hip caused by OA would reduce the load on the hip by decreasing the gluteus medius activity. The abduction moment values of the hip joint represent the abductor muscle strength of the hip joint during gait.¹¹ The frontal pelvic obliquity on the weight-bearing limb corresponding to a Trendelenburg's sign is related to a painful hip.⁴ In this study, we could also observed decreased hip abduction moment and Trendelenburg's sign to minimize the load on their painful hip. We hypothesize that the load acting on the lumbar spine was increased by adopting an antalgic mechanism.

In this study, we selected patients with end-stage hip osteoarthritis, but not those with a mild to moderate form of the disease. This study supports the importance of physical therapy for BHO patients to maintain a normal hip extension angle at the push-off phase. Moreover, improvement in the hip extension angle may lead to less loading of ankle plantarflexors and less lumbar lordosis. Presumably, these effects may be remarkable in mild to moderate BHO patients who have not developed firm or nonreversible flexion contracture of the hip.

CONCLUSIONS

Gait analysis that ignored the influence of walking speed was used in this study to define the intrinsic gait characteristics of BHO patients. In the sagittal plane, reduced extension of the hip angle was compensated for by increased cadence, maintained forward tilting of the pelvis, and increased ankle generation power. Moreover, intrinsic gait characteristics in the frontal plane were recognized as narrowed step width, dropped pelvis on the stance side, reduced hip abduction angle, reduced hip abduction moment.

Conflict of interest

The authors did not receive and will not receive any benefits and funding from any commercial party related directly or indirectly to the subject of this article.

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FIGURE LEGENDS

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Figure 1. Photograph of a subject walking on walkway containing four force plates.

Figure 2. Temporal and distance factors.

* $p < 0.05$ (normal subjects at free speed versus BHO patients, and normal subjects at
345 slow speed versus BHO patients).

Table 1. Temporal and walking distance variables* $p < 0.05$ (normal subjects at free
speed versus BHO patients, and normal subjects at slow speed versus BHO
patients).

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Figure 3. Kinematic factors.

* $p < 0.05$ (normal subjects at slow speed versus BHO patients).

Thick line: BHO patients, broken line: normal subjects at free speed, thin line:
normal subjects at slow speed.

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Figure 4. Kinetic factors.

* $p < 0.05$ (normal subjects at slow speed versus BHO patients).

Thick line: BHO patients, broken line: normal subjects at free speed, thin line:
normal subjects at slow speed.

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Table 2. Kinematic and kinetic variables* $p<0.05$ (normal subjects at slow speed versus BHO patients).

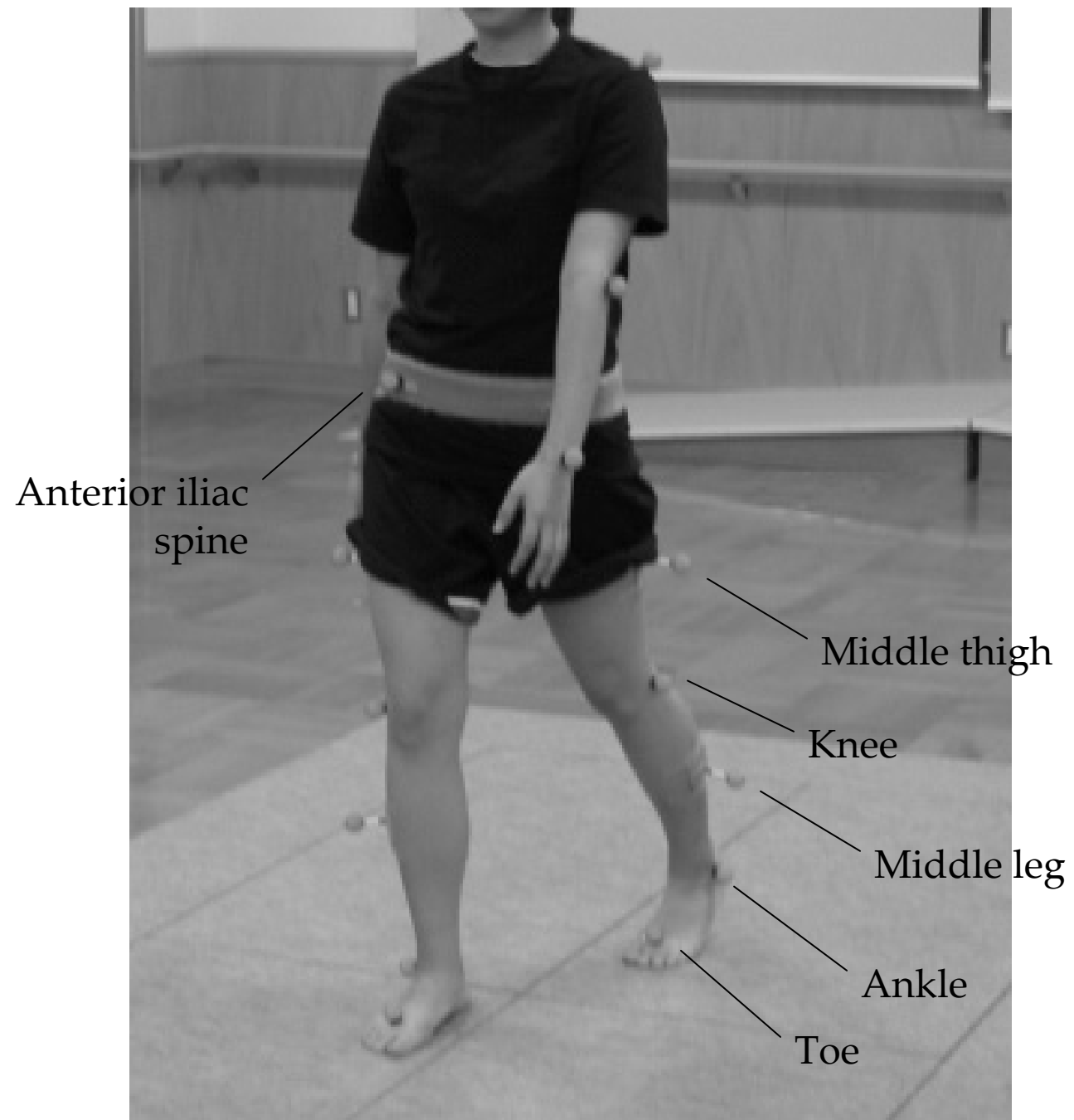


Figure 1.

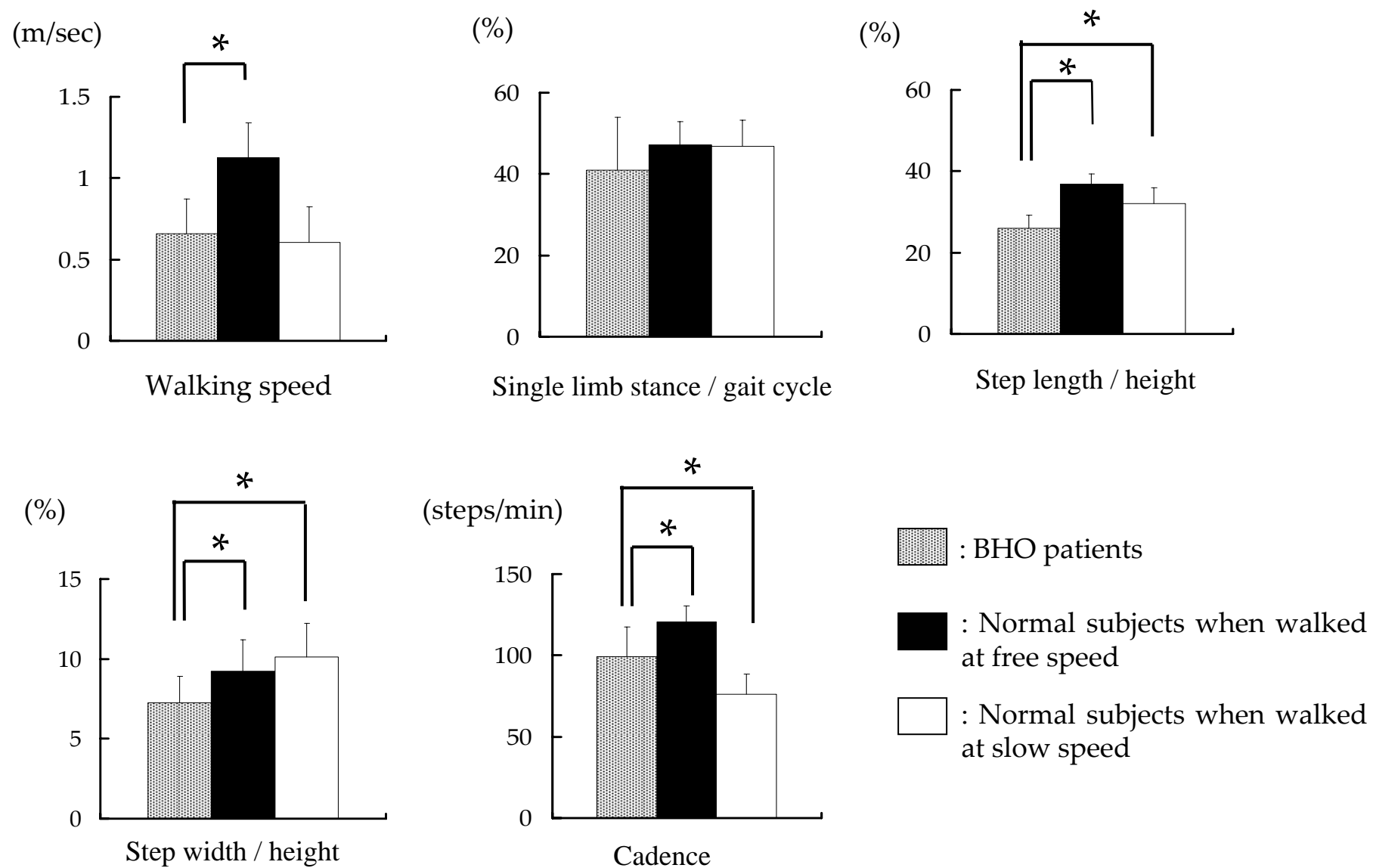
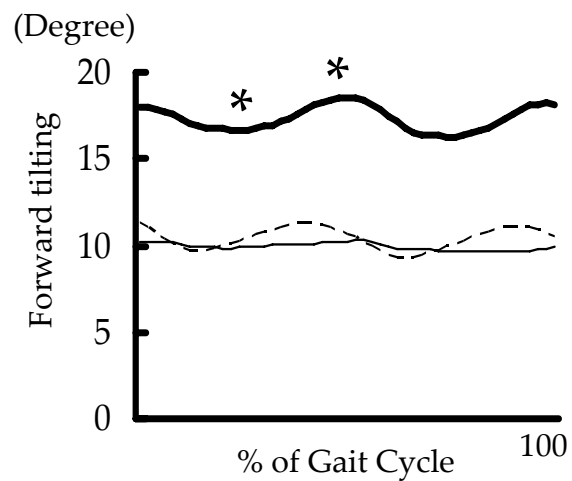


Figure 2.

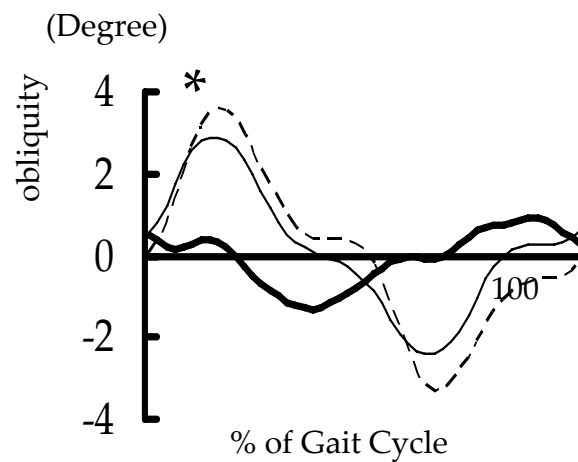
Table 1.

Temporal and walking distance variables

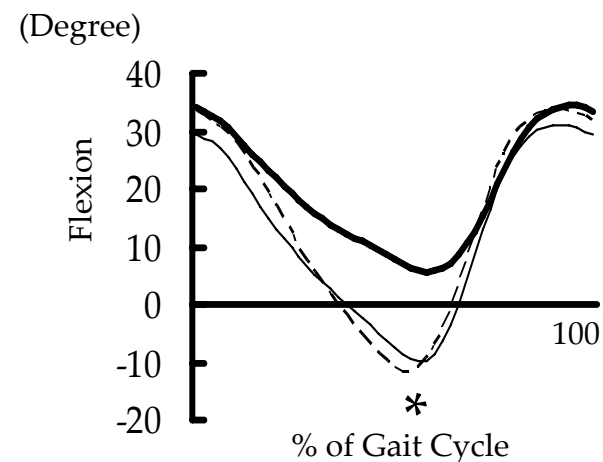
	BHO patients			Normal subjects					
	Mean \pm SD	max	min	Free walking speed			Slow walking speed		
				Mean \pm SD	max	min	Mean \pm SD	max	min
Walking speed (m/s)	0.65 \pm 0.16	0.92	0.40	1.12 \pm 0.15 *	1.48	0.90	0.61 \pm 0.14	0.81	0.41
Single limb stance / gait cycle (%)	41.02 \pm 12.64	55.21	20.24	47.26 \pm 5.62	53.23	37.04	46.79 \pm 6.48	53.57	52.17
Step length / height (%)	26.06 \pm 3.21	32.12	21.67	36.94 \pm 2.42 *	41.36	34.38	32.11 \pm 3.86 *	39.10	25.95
Step width / height (%)	7.25 \pm 1.65	9.87	4.94	9.21 \pm 1.96*	12.41	5.56	10.13 \pm 2.08 *	14.59	7.06
Cadence (steps/min)	99.31 \pm 18.11	123.00	61.02	120.47 \pm 9.95 *	145.38	109.08	75.98 \pm 12.58*	94.74	51.12



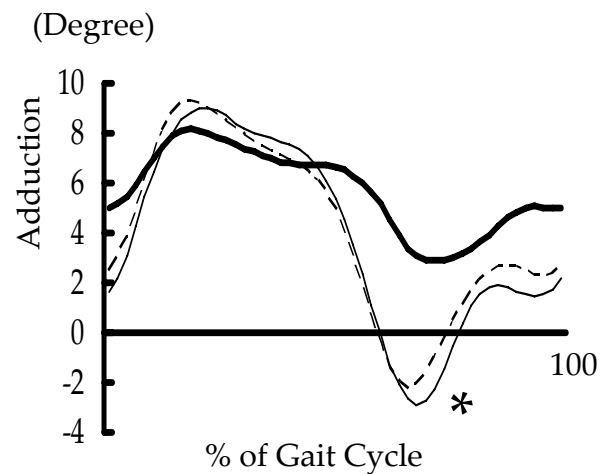
Pelvic angle in the sagittal plane



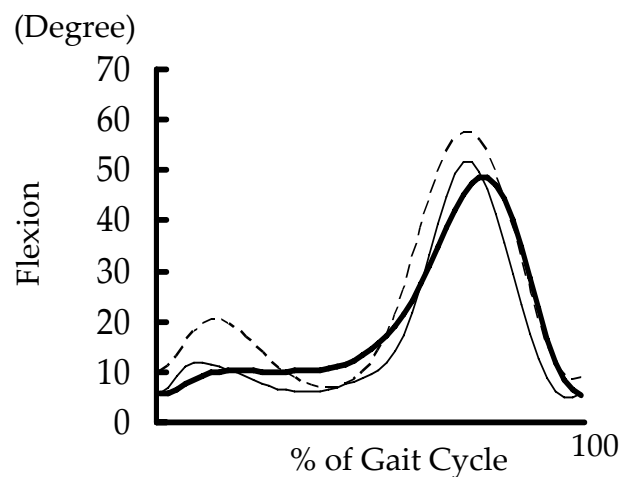
Pelvic angle in the frontal plane



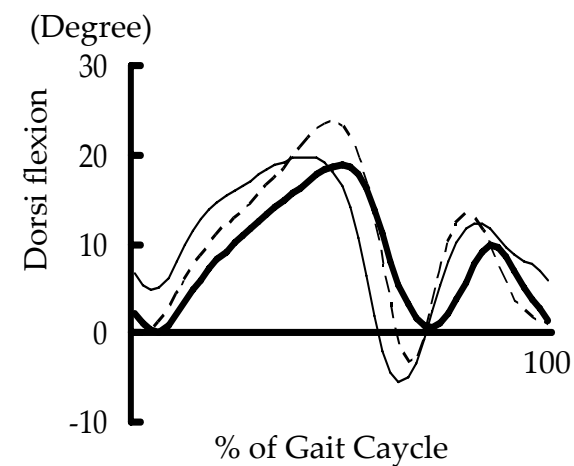
Hip angle in the sagittal plane



Hip angle in the frontal plane



Knee angle in the sagittal plane



Ankle angle in the sagittal plane

Figure 3.

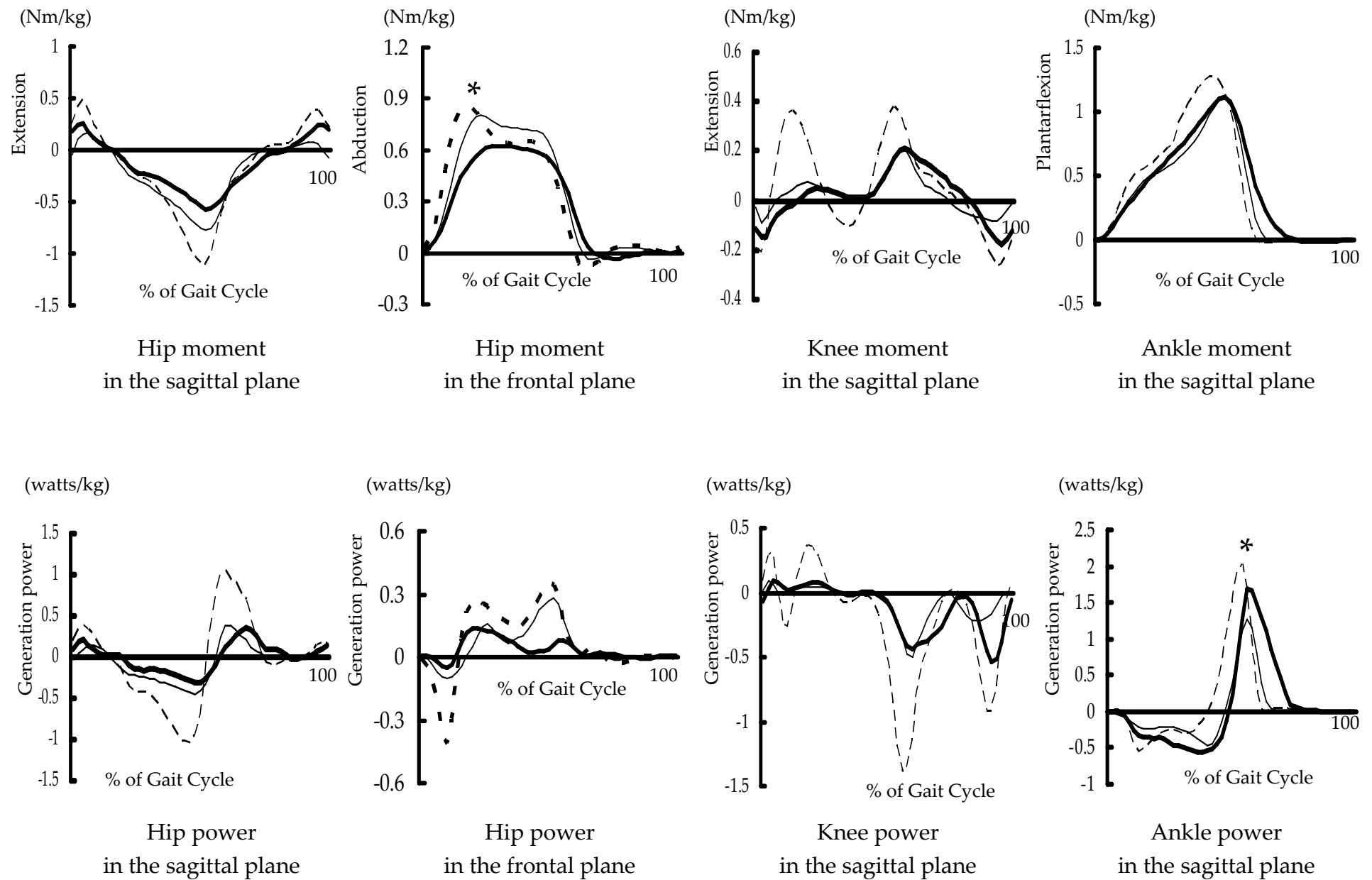


Figure 4.

Table 2.**Kinematic and kinetic variables**

	BHO patients			Normal subjects					
				Free walking speed			Slow walking speed		
	Mean \pm SD	max	min	Mean \pm SD	max	min	Mean \pm SD	max	min
Joint angle (degree)									
Pelvic forward tilting	19.01 \pm 5.28	26.3	9.15	11.53 \pm 4.52	21.48	5.74	10.99 \pm 4.90*	21.00	4.13
Pelvic backward tilting	15.69 \pm 5.67	24.02	2.41	9.02 \pm 4.36	17.61	3.51	8.83 \pm 5.24 *	19.24	2.72
Pelvic positive obliquity	2.38 \pm 1.54	6.27	0.6	3.67 \pm 1.29	5.70	1.29	3.05 \pm 0.97 *	4.63	1.60
Pelvic negative obliquity	-2.55 \pm 0.84	-1.15	-6.03	-3.46 \pm 0.81	-2.34	-4.56	-2.55 \pm 0.85	-1.21	-3.96
Hip flexion	35.50 \pm 10.25	51.28	20.24	34.34 \pm 6.50	51.45	27.4	31.31 \pm 7.41	51.91	22.93
Hip extension	3.93 \pm 6.61	14.23	-8.70	-11.79 \pm 6.45	2.52	-23.47	-10.18 \pm 6.68 *	3.09	-21.91
Hip adduction	8.98 \pm 3.31	13.68	3.11	9.51 \pm 2.49	15.03	7.05	9.27 \pm 2.90	14.69	5.44
Hip abduction	1.96 \pm 2.66	5.12	-2.82	-2.40 \pm 2.79	1.18	-7.07	-3.17 \pm 3.16 *	1.29	-9.59
Ankle dorsiflexion	19.01 \pm 5.01	27.94	10.12	23.86 \pm 7.94	36.87	10.63	20.39 \pm 7.59	39.80	14.74
Ankle plantarflexion	-1.40 \pm 4.93	2.70	-12.02	-6.14 \pm 7.36	11.73	-17.87	-4.67 \pm 8.71	11.69	-24.72
Joint moment (Nm/kg)									
Hip extension	0.32 \pm 0.08	0.45	0.19	0.51 \pm 0.24	1.16	0.30	0.23 \pm 0.17	0.68	0.05
Hip flexion	-0.61 \pm 0.23	-0.23	-0.98	-1.12 \pm 0.24	-0.68	-1.51	-0.80 \pm 0.25	-0.45	-1.30
Hip abduction	0.68 \pm 0.14	0.86	0.39	0.88 \pm 0.13	1.12	0.61	0.83 \pm 0.10 *	0.97	0.68
Hip adduction	-0.08 \pm 0.03	-0.03	-0.13	-0.13 \pm 0.06	-0.05	-0.28	-0.05 \pm 0.04	0.00	-0.14
Joint Power (Watts/kg)									
Hip generation	0.52 \pm 0.26	0.71	0.06	1.18 \pm 0.36	1.84	0.22	0.43 \pm 0.24	1.02	0.03
Hip absorption	-0.41 \pm 0.26	-0.12	-0.95	-1.16 \pm 0.23	-0.72	-1.67	-0.50 \pm 0.21	-0.15	-0.79
Ankle generation	1.82 \pm 0.63	2.93	0.50	2.10 \pm 0.56	3.34	1.49	1.35 \pm 0.43 *	2.02	0.60
Ankle absorption	-0.63 \pm 0.20	-0.32	-0.89	-0.64 \pm 0.21	-0.39	-1.05	-0.50 \pm 0.15	-0.25	-0.75