1 **Dynamic hip joint stiffness in individuals with total hip arthroplasty:**
2 **Relationships between hip impairments and dynamics of the other joints**
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ABSTRACT

Background.

Little is known about hip joint stiffness during walking (dynamic joint stiffness) and the effect of hip impairments on biomechanical alterations of other joints in patients with total hip arthroplasty.

Methods.

Twenty-four patients (mean age 61.7 years) who underwent unilateral (n = 12) or bilateral total hip arthroplasty (n = 12) and healthy subjects (n = 12) were recruited. In addition to kinematic and kinetic variables, dynamic hip joint stiffness which was calculated as an angular coefficient of linear regression of the plot of the hip flexion moment versus hip extension angle during the late stance of gait, was measured. Group differences were compared using one-way ANOVA and Tukey's post-hoc test, and relationships between primary hip impairments and secondary gait impairments were found using partial correlation coefficients adjusted for gait speed and stride length.

Findings.

Dynamic hip joint stiffness was 47% higher on the side with the more pronounced limp in patients with bilateral arthroplasty than in healthy controls. In the same patients, increased dynamic hip joint stiffness was significantly associated especially with increased ankle plantarflexion moment on the ipsilateral side. In patients with unilateral arthroplasty,

1 decreased hip power was significantly related to increased ankle plantarflexor power, only on

2 the non-operated side.

3 *Interpretation.*

4 We found that dynamic hip joint stiffness was an important factor in assessing relationships

5 between hip impairments and dynamics in other joints, especially in patients with bilateral

6 total hip arthroplasty. The effects of altering hip joint stiffness on gait biomechanics need to be

7 explored.

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1. Introduction

Total hip arthroplasty (THA) is a widely used and popular method of treating patients with hip osteoarthritis. However, despite the success of the surgery, many studies examining gait in patients who underwent THA have reported residual hip impairments, such as decreased hip extension, decreased hip flexor-extensor and abductor moments of force, and decreased hip power, especially in late stance (Beaulieu et al., 2010; Foucher et al., 2007; Loizeau et al., 1995; Madsen et al., 2004; Miki et al., 2004; Nantel et al., 2009; Perron et al., 2000).

Hip impairments during gait persisting in patients with THA are related to concomitant modifications in the neighboring joints (Perron et al., 2000). Diminished hip extension during gait was correlated with increased knee flexion and occurred simultaneously with increased ankle dorsiflexion and increased pelvic anterior tilt (Miki et al., 2004; Perron et al., 2000). More importantly, increased ankle plantarflexion moment, power, and energy during walking have been observed in patients with THA (Loizeau et al., 1995; Perron et al., 2000). According to these earlier studies, it appears that hip impairments during gait and changes of dynamics in other joints (e.g., increased ankle plantarflexion moment) are most clearly present in late stance; therefore, we need to focus on biomechanical alterations in late stance during gait in patients with THA. Greater moment and power in joints other than the hip joint could be related to higher mechanical load on the joints, possibly causing muscle fatigue, joint pain, or

osteoarthritic change in knee or ankle joints, which are often present as secondary impairments

in patients with THA (Bessette et al., 2003; Umeda et al., 2009). However, it is still not clear

which hip impairments affect kinetic alterations in other joints, such as increased ankle

moment and power in patients with THA. Although decreased hip extension during walking is

the gait impairment generally observed in patients with THA (Miki et al., 2004; Perron et al.,

2000), a significant correlation between decreased hip extension and increased ankle moment

and power has not been identified. Possibly, it might be necessary to investigate an alternative

gait parameter that could be related to biomechanics in the other joints.

From a biomechanical perspective, joint stiffness during walking -dynamic joint

stiffness- can be estimated directly by using 3-dimensional gait analysis. Dynamic joint

stiffness has been defined as the change in joint moment divided by the change in joint angle

(Butler et al., 2003; Farley et al., 1998), and it can be determined by calculating the slope of

the line in which the joint moment is plotted against the joint angle (Butler et al., 2003; Davis

and DeLuca, 1996; Farley et al.,1998). Dynamic joint stiffness differs from passive joint

stiffness in that the former may result from active muscle contraction (either eccentric or

concentric) and/or through passive soft tissue strain (Davis and DeLuca, 1996).

Recently, higher dynamic joint stiffness in the knee has been observed in patients with

knee osteoarthritis (Dixon et al., 2010; Zeni and Hingginson, 2009). While some level of

stiffness is required for optimal utilization of the stretch-shortening cycle and maintenance of

1   joint stability, too much stiffness may be associated with bone and joint impairments such as

2   stress fractures and osteoarthritis (Butler et al., 2003; Childs et al., 2004; Schmitt and Rudolph,

3   2008). Furthermore, increased dynamic joint stiffness is also associated with increased

4   mechanical load on other joints (Hamill et al., 2009). However, it is currently unknown

5   whether patients with THA have higher dynamic joint stiffness in the hip. If this is the case,

6   dynamic joint stiffness may affect biomechanics, not only in the hip joint but also in other

7   joints.

8   Moreover, to date, no studies have examined the influence of hip impairments on gait

9   adaptation for patients who underwent bilateral vs. unilateral THA separately despite the fact

10   that a difference in gait ability between the two groups has been noted previously (Berman et

11   al., 1991; Wykman and Olsson, 1992). Patients with unilateral THA may actively utilize the

12   non-operated side rather than the operated side to compensate for hip impairments. The

13   purposes of this study were (1) to evaluate dynamic hip joint stiffness, in addition to joint

14   angle, moment, and power at the hip and other joints, in patients with bilateral or unilateral

15   THA relative to healthy individuals, and (2) to investigate the influence of hip impairments

16   including dynamic hip joint stiffness on kinematic and kinetic variables of other joints in both

17   patients who underwent unilateral and bilateral THA. We hypothesized that dynamic hip joint

18   stiffness would be higher in patients with THA than in healthy individuals, and that increased

19   dynamic hip joint stiffness would relate to increased moment and power production at the knee

1 or ankle.

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2. Methods

2.1. Subjects

To avoid the period when a major change is produced in gait ability after an operation (Madsen et al., 2004; Miki et al., 2004; Tanaka et al., 2009), 24 female patients who underwent THA more than 6 months previously and had completed standard postoperative rehabilitation were recruited from a local patient association. Twelve patients who had undergone bilateral THA, and the other twelve patients who had undergone unilateral THA. Their age range was 50−74 years (61.7 (6.8); mean (SD)). Their body weight range was 38.4−89.8 kg (52.3 (10.4)), and their height range was 144.0−167.0 cm (153.9 (5.5)). Their body mass index range was 16.6−32.2 (22.0 (3.6)). The Harris hip score range of the patients was 61−99 points (86.3 (10.9)). The indication for replacement was painful hip osteoarthritis, and the range of implantation time was 10−56 months (35.0 (15.5)). Although there was a range of implantation time, no significant correlation between implantation time and any gait variable and no significant difference in implantation time between patients with bilateral and unilateral THA were observed. Patients were excluded from the study if they had musculoskeletal conditions other than THA or if they had been diagnosed with neurological

disorders or cardiovascular disease that limited their function. Patients with leg-length

discrepancies of over 20 mm were excluded because such discrepancies are expected to

significantly impair walking ability (Gurney, 2002). Patients were all able to walk

independently without an assistive device. Age-matched control participants (12 females) were

recruited for the study. All of the control participants were free from orthopedic, neurological,

and cardiovascular abnormalities. Participants provided informed consent, and the protocol

was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty

of Medicine.

2.2. Gait measurement

Body kinematics were recorded using a 6-camera Vicon motion system (Vicon Nexus;

Vicon Motion Systems Ltd. Oxford, England) at a sampling rate of 200Hz. The subjects were

clothed in close fitting shorts and T-shirts, and reflective markers were attached to the body of

each participant according to the Vicon Plug-in-Gait marker placement protocol (lower body)

by a single investigator. Sixteen markers were placed bilaterally on the anterior superior iliac

spine, posterior superior iliac spine, lateral thigh, lateral femoral epicondyle, lateral shank,

lateral malleolus, second metatarsal head, and calcaneus. All data were low-pass filtered using

a Woltring filter with a cut-off frequency of 6 Hz. Two force plates (Kistler Japan Co., Ltd.

Tokyo, Japan) were used to measure the ground reaction force at a sampling rate of 1000 Hz.

1   Before data collection, each camera was calibrated, and the force plates were balanced.

2   The subjects were allowed to walk on the walkway at least 10 times to familiarize

3   themselves with the environment before the actual trials. Walking was recorded at self-selected

4   speed. At least 3 successful trials for each subject were recorded for subsequent analysis.

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6   *2.3. Data reduction*

7   We analyzed data of both sides for patients with unilateral or bilateral THA. For each

8   patient with bilateral THA, the affected side exhibiting the more pronounced limp was

9   determined by observational gait analysis performed by 2 physical therapists, one with 12

10   years of experience, and the other with 9 years of experience. The determination by the 2

11   examiners was completely in agreement for all patients. The non-dominant leg was analyzed

12   for control participants. The leg used to kick a ball was identified as the dominant leg.

13   Vicon Clinical Manager software was used to calculate the basic gait parameters

14   (walking speed, stride length), relative angles between coordinate systems of each segment in

15   the lower limb, and to estimate the moment and power in each joint from kinematic data and

16   ground reaction force. The peak values of the joint angle, moment, and power were calculated

17   in the sagittal plane. The joint moments were expressed as internal moments. The peak values

18   of the powers were labeled according to Eng and Winter (1995). At the hip, H1 represents

19   power generation by the hip extensors, H2 represents absorption of power by hip flexors, and

1   H3 corresponds to generation of power by the hip flexors. The power phases of the knee were

2   defined as power absorption by the knee extensors in the early stance (K1) and in late stance

3   phase (K3), and power generation by the knee extensors (K2). At the ankle, power absorption

4   (A1) and power generation (A2) by the ankle planter flexors were defined. The values for joint

5   moment (in Newton-meters) and power (in Watts) were normalized with respect to subject

6   body mass (in kilograms).

7   Dynamic joint stiffness at the hip was calculated for each trial. Dynamic joint stiffness

8   was expressed by plotting the values of hip flexion moment versus hip extension angle during

9   late stance, from the onset of the hip flexion moment to the angle at which the hip reached its

10   peak extension (Fig. 1). The angular coefficient of linear regression during late stance

11   corresponded to the joint stiffness index as described in previous studies (Davis and DeLuca,

12   1996; Frigo et al., 1996; Galli et al., 2008). Mean values from three trials for each of the 3

13   sessions were calculated and used for analysis.

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15   *2.4. Statistical analysis*

16   The SPSS 17.0 statistical analysis package (SPSS Inc.) was used for all the statistical

17   analyses of the present study. Demographic characteristics of the patients and control group

18   were compared by one-way analysis of variance (ANOVA) and Tukey's post-hoc test.

19   Comparisons of the spatiotemporal, kinematic, and kinetic variables during gait, and dynamic

20   joint stiffness of the hip among the 3 groups were performed using one-way ANOVA and

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1   Tukey's post-hoc test. We calculated partial correlation coefficients between hip impairments

2   and other gait variables adjusted for gait speed and stride length, for patients with unilateral vs.

3   bilateral THA. For the correlation analysis, only hip variables for which significant differences

4   were confirmed by the comparison between patients and the control group were included as

5   hip impairments. If several correlations between hip impairments and variables in the other

6   joints were detected, a stepwise multiple regression analysis was performed. Additionally, we

7   evaluated the relationship between dynamic hip joint stiffness and potentially relevant

8   variables (i.e., hip extension angle and hip flexion moment). The statistical significance was

9   set at the level of $P < 0.05$.

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12   **3. Results**

13   *3.1. Demographic characteristics and Harris hip score*

14   There was no significant difference among the groups regarding age, weight, height, and

15   body mass index. There was no significant difference in the Harris hip score between the

16   unilateral and bilateral THA groups (Table 1).

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18   *3.2. Comparison of gait parameters between groups*

19   There were no significant differences in gait speed and stride length among the groups

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(Table 1).

Dynamic hip joint stiffness was significantly different, with an increase of 47%, between the control group and the side exhibiting the more pronounced limp in the bilateral THA group (Fig. 2).

Although there was no significant difference in the joint angle and moment between the unilateral THA group and the control group (Fig. 3-A, B), the unilateral THA group exhibited significantly decreased hip flexor power absorption (H2) on the ipsilateral side and decreased hip flexor power generation (H3) on both sides compared with the values in the control group (Fig. 3-C). In addition, the contralateral side of the unilateral THA group showed significantly greater hip extension angle than the more affected side of the bilateral THA group.

The bilateral THA group exhibited a significantly smaller hip extension angle, flexion moment, H2, and H3 on the both sides relative to those of the control group (Fig. 3-A, B, C). By contrast, the bilateral THA group had significantly greater ankle plantarflexor power generation (A2), especially on the more affected side, than the control group (Fig. 3-C).

3.3. Relationships among dynamic hip joint stiffness, hip extension angle, and hip flexion moment

In the unilateral THA group, increased dynamic hip joint stiffness was significantly associated with decreased hip extension angle ($r = -0.84$, $P < 0.01$); however, there were no

significant relationships between dynamic hip joint stiffness and hip flexion moment ($r = -0.36$, $P = 0.31$). In the bilateral THA group, no significant correlations were found between dynamic hip joint stiffness and hip extension angle ($r = -0.18$, $P = 0.62$) or between dynamic hip joint stiffness and hip flexion moment ($r = -0.05$, $P = 0.88$).

3.4. Relationship between hip impairments and gait parameters in the unilateral and bilateral THA groups

3.4.1. Correlations in the unilateral THA group

Significant correlations between hip flexor power absorption and generation (H2 and H3), which were lower than the control group, and other gait variables are shown in Table 2. The decreased H2 was significantly related to the increased ankle plantarflexor power absorption (A1: $r = -0.76$, $P = 0.01$) and increased ankle plantarflexor power generation (A2: $r = -0.76$, $P = 0.01$).

3.4.2. Correlations in the bilateral THA group

Patients with bilateral THA showed significant increases in dynamic hip joint stiffness and significant decreases in the hip extension angle, hip flexion moment, and hip flexor power absorption and generation (H2 and H3) compared with those in the control group; therefore, relationships between these hip impairments and other gait variables were investigated.

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1   Increased dynamic hip joint stiffness was significantly associated with increased ankle

2   plantarflexion moment ($r = 0.89$, $P < 0.01$; $r = 0.83$, $P < 0.01$) and ankle plantarflexor power

3   generation (A2: $r = 0.78$, $P < 0.01$; $r = 0.83$, $P < 0.01$) on both sides and with increased ankle

4   plantarflexor power absorption (A1: $r = 0.75$, $P = 0.01$) on the contralateral side (Table 3). In

5   addition, increased dynamic hip joint stiffness was also significantly related to the increased

6   hip extensor power generation (H1) on the ipsilateral side ($r = 0.64$, $P = 0.04$) and the

7   contralateral side ($r = 0.72$, $P = 0.02$; Table 3). In multiple regression analysis, ankle

8   plantarflexion moment on the ipsilateral side was taken as an independent variable for

9   dynamic hip joint stiffness (adjusted $R^2 = 0.64$, $P < 0.01$).

10   Furthermore, decreased hip flexor power generation (H3) was significantly correlated

11   with increased knee extensor power absorption (K1) on the contralateral side ($r = 0.74$, $P =$

12   0.01; Table 3).

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15   **4. Discussion**

16   The primary findings of the current study were that dynamic hip joint stiffness was

17   higher in the bilateral THA group than in the control group, and increased dynamic hip joint

18   stiffness was associated especially with increased ankle plantarflexion moment for patients

19   with bilateral THA. We also found that in the unilateral THA group, decreased hip flexor

1 power in late stance was related to increased ankle plantarflexor power on the non-operated

2 side.

3   There were no significant differences in gait speed and stride length among the groups

4 in the present study. This result agrees with the findings of a previous study by Berman et al.

5 (1991), who showed that, after the 12th postoperative month, gait speed was not significantly

6 different between normal individuals and patients with unilateral or bilateral THA. This

7 similar gait speed among groups allowed us to compare the kinematic and kinetic variables

8 because large differences in gait velocity may influence gait biomechanics (Lelas et al., 2003).

9   The primary purpose of this study was to evaluate hip joint stiffness during walking in

10 patients with bilateral or unilateral THA relative to that in healthy individuals. As a result of

11 group comparison, patients with bilateral THA exhibited higher dynamic hip joint stiffness on

12 the side with the more pronounced limp than healthy controls in spite of the same gait speed

13 and stride length in the 2 groups (Fig. 2). In general, increased dynamic hip joint stiffness in

14 late stance is thought to result from decreased hip extension angle and increased hip flexion

15 moment. However, in our results, dynamic hip joint stiffness in the bilateral THA group did

16 not have a significant relationship with the hip extension angle and the hip flexion moment.

17 This finding suggests the importance of including dynamic hip joint stiffness as a variable in

18 the gait analysis of patients with THA. On the other hand, the unilateral THA group showed no

19 significant increase of dynamic hip joint stiffness. The hip extension angle of the opposite side

1 in patients with unilateral THA was larger than that of the more affected side of patients with

2 bilateral THA. The opposite hip joint, in which the flexibility was relatively maintained, might

3 influence the motion of the operated hip joint through the pelvis, and consequently, bilateral

4 hip joint stiffness may not be increased excessively in patients with unilateral THA.

5 In late stance, uniarticular hip flexors and some passive hip structures (e.g., ligaments,

6 tendon, and tissue) are stretched due to hip extension. Furthermore, eccentric contraction of

7 the hip flexor muscle followed by concentric contraction will control the forward movement of

8 the center of mass and pull the leg into the swing phase (McGibbon, 2003; Sadeghi et al,

9 2001). Therefore, dynamic hip joint stiffness as calculated in the current study represents

10 stiffness of the passive hip structure with eccentric contraction of the hip flexor muscle. A

11 previous study has reported persistent muscle atrophy and fat infiltration in the iliopsoas in

12 patients 2 years after THA (Rasch et al., 2009). This persistent muscle dysfunction estimated

13 from the previous study and the lower hip extension excursion detected in the current study

14 may comprise a stiffening strategy to stabilize the affected hip joint during late stance.

15 Meanwhile, excessive dynamic joint stiffness would result in increased bone and joint load

16 (Butler et al., 2003), potentially causing changes of the loading condition on the implant and

17 possibly resulting in a higher risk of implant loosening (Kilgus et al., 1991; Kleemann et al.,

18 2003). Therefore, emphasis on the assessment of dynamic hip joint stiffness would be needed,

19 especially for patients with bilateral THA.

1   The secondary purpose of the current study was to investigate the relationships between

2   hip impairments and changes of dynamics in the other joints in patients with unilateral or

3   bilateral THA separately. For the bilateral THA group, increased dynamic hip joint stiffness

4   was significantly associated especially with increased ankle plantarflexion moment of the

5   ipsilateral side. Increased ankle plantarflexion moment has already been reported for patients

6   who underwent THA (Perron et al., 2000). However, to date, which hip impairment affects the

7   increase in ankle moment is unknown. The current study provides the first indication that

8   higher dynamic hip joint stiffness can lead to higher ankle plantarflexion moment, especially

9   in the patients after bilateral THA. In the current study, this relationship was elucidated by

10   analyzing dynamic hip joint stiffness in addition to the conventional gait variables. Some level

11   of joint stiffness is required for efficient utilization of the stored elastic energy in the

12   musculoskeletal system (Butler et al., 2003). However, excessive joint stiffness could inhibit

13   the storage of energy in the muscle (Butler et al., 2003), resulting in a loss of the functional

14   role of the hip flexor muscle, which pulls the leg forward to assist with swing initiation. Ankle

15   plantarflexor muscles also contribute to forward progression of the leg into the swing phase

16   (Neptune et al., 2001), thus swing initiation can be achieved by interaction and coordination

17   between the hip flexor and ankle plantarflexor muscles (McGibbon, 2003; Sadeghi et al, 2001).

18   Therefore, increased ankle plantarflexion moment might be interpreted as a compensatory

19   mechanism for the increased hip joint stiffness that would be related to decreased hip flexor

1   muscle function during late stance.

2   On the other hand, in the unilateral THA patients, there was no significant relationship

3   between hip impairments and ankle plantarflexion moment and power on the ipsilateral side,

4   even though these patients had lower hip flexor power absorption (H2) and generation (H3)

5   than the healthy controls. How did patients with unilateral THA compensate for hip

6   impairments to walk at the same speed as healthy controls? Interestingly, decreased H2 on the

7   operated side was significantly related to the increased ankle plantarflexor power absorption

8   and generation (A1 and A2) on the contralateral side (Table 2). This finding indicates that the

9   patients with unilateral THA tend to actively utilize ankle plantarflexor power on the

10   non-operated side, rather than increase ankle power on the operated side.

11   In the bilateral THA group, decreased hip flexor power generation (H3) was related to

12   increased knee extensor power absorption during early stance (K1) on the contralateral side

13   (Table 3). A previous study utilizing radiographic evaluation has reported that 33% of subjects

14   with unilateral THA showed progression of osteoarthritis on the contralateral knee (Umeda et

15   al., 2009). Although the prevalence of knee osteoarthritis in patients with bilateral THA has

16   not been investigated, our results suggested that patients with bilateral THA who have greatly

17   diminished hip power in late stance might develop knee pathology on the contralateral side.

18   Some limitations to the present study should be mentioned. Because we excluded

19   patients with comorbidities, the patients in this study consisted of relatively healthy

1   post-operative patients. Different results may be obtained from patients with knee and ankle

2   impairments or patients in the acute stage after the operation. Another limitation was that

3   contributing factors such as passive and active elements that alter dynamic hip joint stiffness

4   were not clearly discriminated. Therefore, the most effective therapeutic approach for the

5   reduction of dynamic hip joint stiffness remains unknown. Butler et al. (2003) suggested that

6   dynamic joint stiffness is altered through the retraining of movement patterns and that the

7   alteration can influence the loads experienced by the lower extremities. Further research is

8   warranted on contributing factors and effective approaches for dynamic hip joint stiffness in

9   patients with THA.

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12   **5. Conclusions**

13   Patients with bilateral THA exhibited increased dynamic hip joint stiffness on the side

14   exhibiting the more pronounced limp compared with the gait of healthy normals. In patients

15   with bilateral THA, increased dynamic hip joint stiffness was associated especially with

16   increased ankle plantarflexion moment on the ipsilateral side. Additionally, lower hip power

17   generation in late stance was related to greater power absorption on the contralateral knee joint

18   in the early stance. Meanwhile, in patients with unilateral THA, decreased hip power was

19   associated with increased ankle power on the non-operated side. Clinicians may need to focus

on releasing dynamic hip joint stiffness as well as increasing hip power to prevent overload at

the knee and ankle joints during postoperative rehabilitation for patients with THA.

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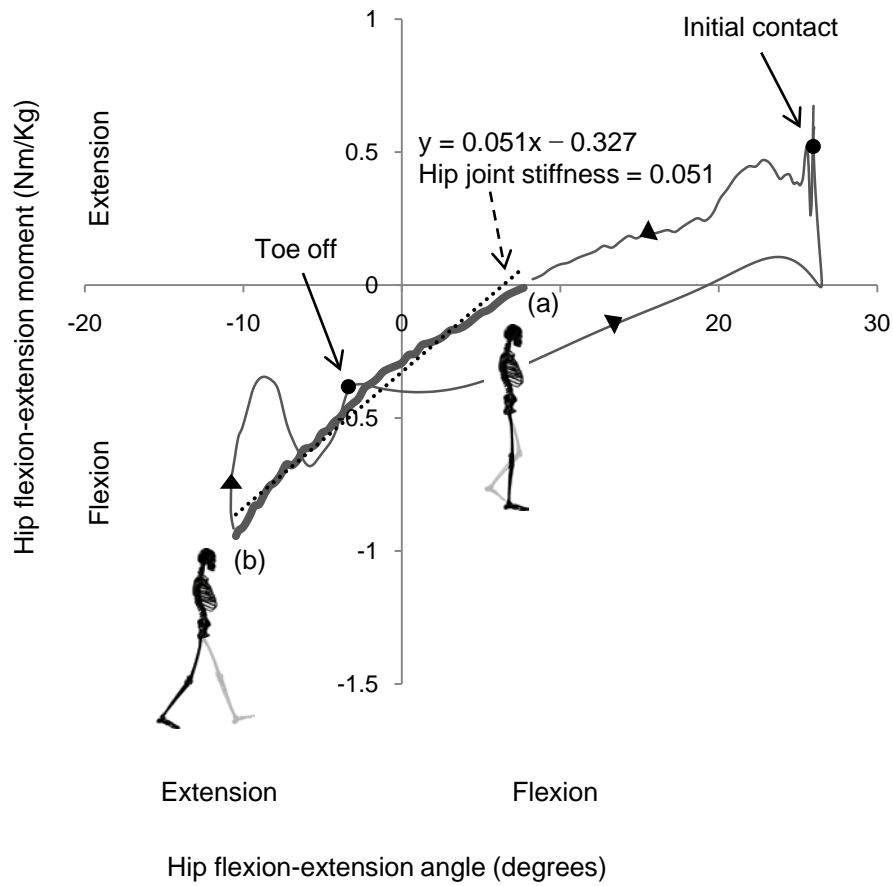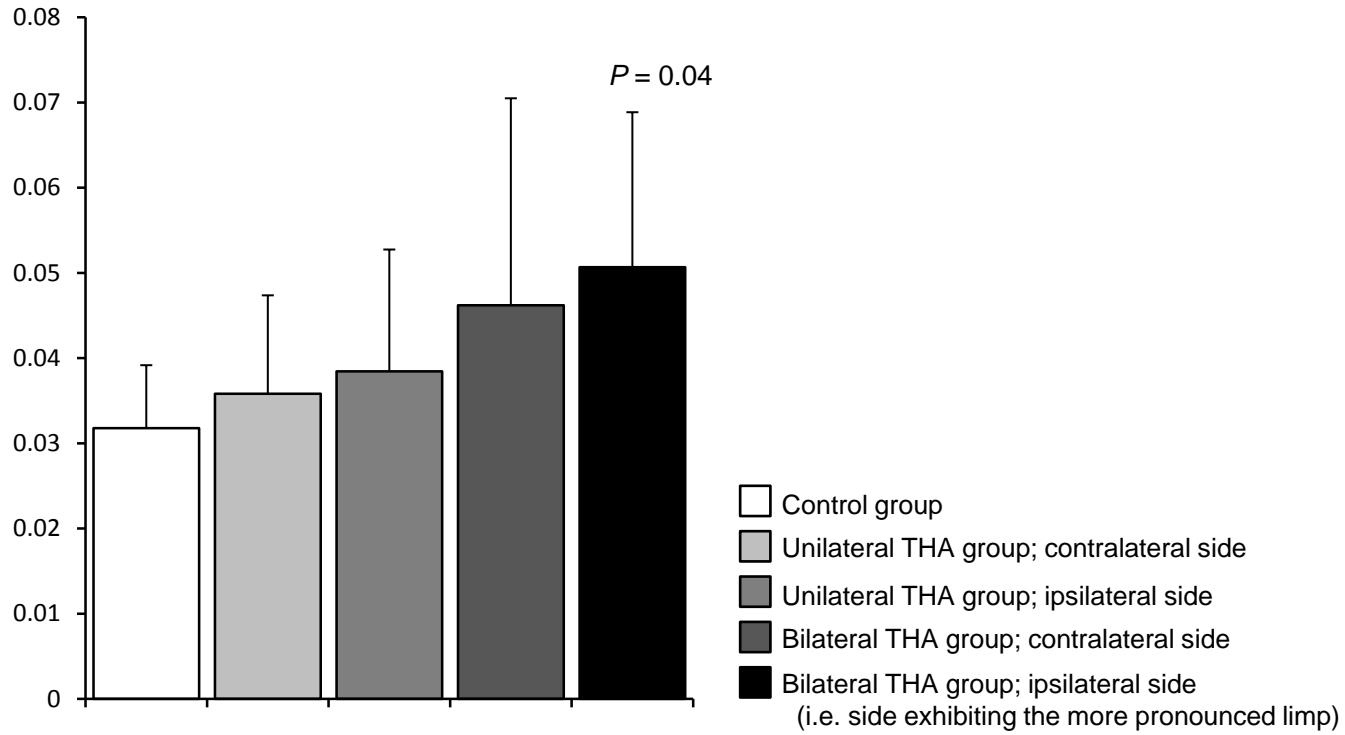9   increase in severity of knee osteoarthritis. Clin. Biomech. 24, 366–371.
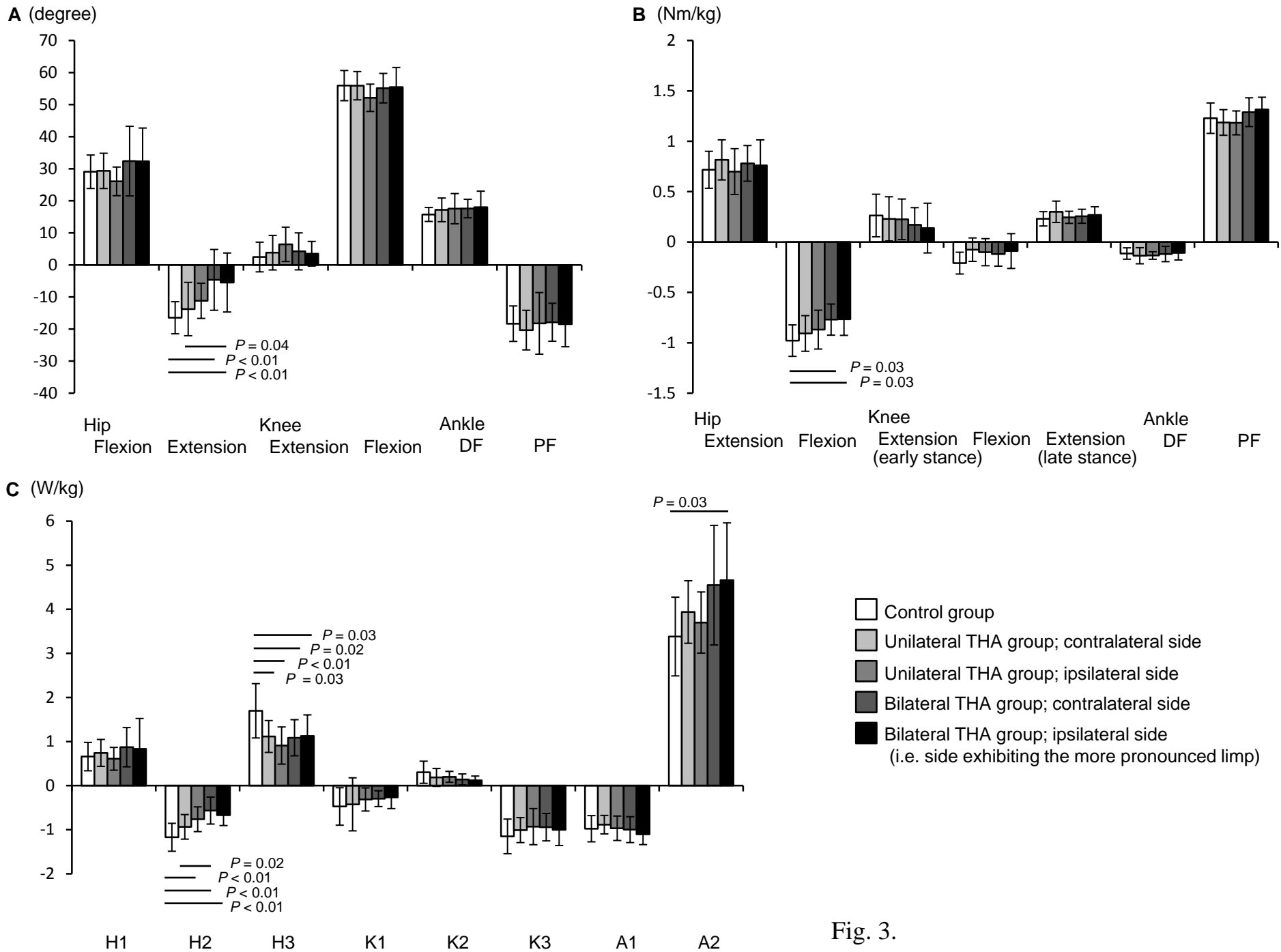
Fig. 1.

Fig. 2.

Fig. 3.

Figure legends

Fig. 1. Hip angle-moment plot during the gait cycle for a patient. Dynamic joint stiffness at the hip was calculated as the slope of the linear regression line during the late stance (thick line) from the onset of the hip flexion moment (a) to the angle at which hip reached its peak extension (b).

Fig. 2. Differences in hip dynamic joint stiffness. The bilateral THA group had significantly higher hip stiffness on the ipsilateral side than the control group.

Fig. 3. Group differences in joint angle (A), joint moment (B), joint power (C), and hip dynamic joint stiffness during gait. DF, dorsiflexion; PF, plantarflexion; H1, hip extensor power generation; H2, hip flexor power absorption; H3, hip flexor power generation; K1, knee extensor power absorption in early stance; K2, knee extensor power generation; K3, knee extensor power absorption in late stance; A1, ankle plantar-flexor power absorption; A2, ankle plantarflexor power generation.

Table 1

Demographic characteristics, Harris hip score, and spatiotemporal gait parameters for control and patient groups

	Control group (n = 12)		Unilateral THA group (n = 12)		Bilateral THA group (n = 12)		P-value
	Mean	(SD)	Mean	(SD)	Mean	(SD)	
Age (y)	63.4	(5.1)	63.2	(7.2)	60.3	(6.4)	0.40[a]
Weight (kg)	50.9	(5.4)	52.2	(7.1)	52.3	(13.3)	0.32[a]
Height (cm)	153.3	(4.5)	152.4	(5.1)	155.5	(5.6)	0.92[a]
Body mass index	21.6	(2.1)	22.5	(3.3)	21.4	(3.9)	0.67[a]
Harris hip score total/100	—	—	85.3	(12.5)	87.3	(9.5)	0.29[b]
Gait speed (m/s)	1.11	(0.11)	1.09	(0.09)	1.09	(0.12)	0.91[a]
Stride length (m)	1.15	(0.64)	1.15	(0.05)	1.15	(0.07)	0.97[a]

(Foot-notes for Table 1)

[a] The effects of Group in a one-way ANOVA

[b] Unpaired t-test

Table 2

Significant partial correlations between hip impairments and kinematic or kinetic variables during gait in the unilateral THA group

Hip impairments during gait	vs. Ipsilateral		vs. Contralateral	
		R value [a]		*R* value [a]
Hip flexor power absorption (H2)	Hip flexion moment	0.75*	H2	0.82**
	K1	0.70*	A1	−0.76*
			A2	−0.76*
Hip flexor power generation (H3)			Hip extension moment	0.80**

(Foot-notes for Table 2)

All gait variables were converted to the positive value for the correlation analysis to facilitate the interpretation of the results of analysis.

[a] Partial correlation coefficients adjusted for gait speed and stride length.

K1, knee extensor power absorption in early stance; A1, ankle plantarflexor power absorption; A2, ankle plantarflexor power generation.

* $P < 0.05$, ** $P < 0.01$

Table 3

Significant partial correlations between hip impairments and kinematic or kinetic variables during gait in the bilateral THA group

Hip impairments during gait	vs. Ipsilateral		vs. Contralateral	
		R value [a]		R value [a]
Hip dynamic joint stiffness	Ankle plantarflexion moment[b]	0.89**	Ankle plantarflexion moment	0.83**
	H1	0.64*	H1	0.72*
	A2	0.78**	A1	0.75*
			A2	0.83**
Hip extension angle	Hip flexion angle	−0.92**	Hip flexion angle	−0.86**
	Hip flexion moment	0.82**	Hip extension angle	0.96**
	H2	0.74*	Hip flexion moment	0.70*
Hip flexion moment	Hip flexion angle	−0.75*	Hip flexion angle	−0.71*
	Hip extension angle	0.82**	Hip extension angle	0.77**
	H2	0.74**		
Hip flexor power absorption (H2)	Hip extension angle	0.74*	Hip flexion angle	−0.68*
	Hip flexion moment	0.74*	Hip flexion moment	0.64*
			H1	−0.72*
Hip flexor power generation (H3)			K1	−0.74*

(Foot-notes for Table 3)

All gait variables were converted to the positive value for the correlation analysis to facilitate the interpretation of the results of analysis.

[a] Partial correlation coefficients adjusted for gait speed and stride length.

[b] Ankle plantarflexion moment on the ipsilateral side was taken as an independent variable for dynamic hip joint stiffness (adjusted $R^2 = 0.64$, $P < 0.01$).

H1, hip extensor power generation; K1, knee extensor power absorption in early stance; A1, ankle plantarflexor power absorption; A2, ankle plantarflexor power generation.

* $P < 0.05$, ** $P < 0.01$