Immediate effects of different ankle pushoff instructions during walking exercise on hip kinematics and kinetics in individuals with total hip arthroplasty

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Acknowledgements

This study was supported by Grant-in-Aid for young Scientists (B) No. 20700424 from the ministry of education, culture, sports, science and technology.

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Abstract

Residual hip impairments, such as decreased hip muscle moment and power during walking, have been reported in patients with total hip arthroplasty (THA). Meanwhile, greater ankle power has also been reported in these patients. We investigated the interaction between hip and ankle joints during walking to determine the effects of different ankle pushoff instructions on hip biomechanics in patients with THA. Twenty-four women (age, 60.8 ± 5.5 years) were randomly assigned to walking exercise groups with either decreased pushoff or increased pushoff. Patients in the decreased pushoff group and increased pushoff group were given the instructions "push less with your foot when you walk" and "push more with your foot when you walk," respectively. Exercises lasted approximately 10-15 min. A series of gait-related parameters were analyzed during pre-exercise, exercise, and post-exercise session. In the decreased ankle pushoff group, hip flexor power absorption and hip/ankle power ratio were higher during post-exercise than during pre-exercise. An increase in hip power from −9.8 to 32.1% was identified. The effect of increase in the hip power by the decreasing ankle pushoff was higher in the patients with greater ankle pushoff in their natural gaits. The patients in the increased ankle pushoff group showed decreased hip flexion angle and hip muscle moment and power after the walking exercise, although ankle pushoff was not increased. Walking exercise with decreased ankle pushoff may help improve the distribution of muscle power between hip flexors and ankle plantarflexors during walking in patients with THA.

1. Introduction

Total hip arthroplasty (THA) is a surgical procedure that usually causes marked decrease in pain and concomitantly improves the functional capacity of patients with hip osteoarthritis. However, despite the success of the surgery, some disabilities in gait such as decreased hip extension, hip flexor-extensor and abductor moments of force, and hip power in the late stance persist up to 4 years after the surgery [1−6].

On the other hand, greater ankle power and increases in ankle energy relative to hip energy during walking have been observed in patients who underwent THA [1,2]. Ankle power contributes to forward progression of the leg into the swing phase as well as stabilization and forward progression of the body during walking [7]. Previous studies have shown that coupled muscle activities between hip flexors and ankle plantarflexors (35−60% gait cycle) contribute to accelerating the leg forward into swing [8,9]. Therefore, the increased ankle pushoff observed in patients with THA appears to be a compensatory mechanism for coping with diminished hip flexors function. Although compensatory ankle action possibly contributes to the reduction in hip joint force, the hip moment and power production during walking may not be improved as long as the patients walk with increased ankle pushoff. A persistent walking pattern that enhances ankle pushoff might induce a delayed recovery of the hip muscle volume reported in patients after THA [10]. Therefore, it is important to facilitate the gait pattern by using hip muscles in the case of patients with THA. However, an appropriate strategy for addressing this problem remains to be elucidated.

Recently, Lewis and Ferris [11] showed that for healthy individuals, instruction to increase ankle pushoff during walking results in lowered hip flexion and extension moment as well as decreased hip power in the late stance. Though a significant effect of decreased ankle pushoff on hip kinetics was not identified in their study, there was an indication that hip kinematics and kinetics could be altered by providing instructions regarding ankle pushoff during walking exercise. However, their study included only healthy young individuals, and the effects of the instructions pertaining to ankle pushoff during the walking exercises on gait biomechanics in patients who have hip impairments have not been investigated.

The primary purpose of this study was to investigate the immediate effect of different instructions regarding ankle pushoff during walking on hip kinematics and kinetics for patients with THA. We hypothesized that hip muscle power would be increased after walking exercise with decreased ankle pushoff. A secondary purpose was to examine the pre-exercise gait pattern for which the walking exercise was more effective. We also hypothesized that walking exercise with decreased ankle pushoff might be more effective in patients who had gait patterns that depend more on the ankle pushoff.

2. Methods

2.1. Patients

Twenty-four women who underwent THA more than 6 months before this study was conducted and had completed standard postoperative rehabilitation were recruited from a local patient association. They were 50−74 years old (60.8 ± 5.5; mean ± SD). The Harris hip score of the patients was 61−99 points (88.6 ± 9.8). The indication for replacement was painful hip osteoarthritis, and the implantation time was 10−59 months (34.6 ± 18.5). Patients were excluded from the study if they had musculoskeletal conditions other than THA or if they had been diagnosed with neurological disorders or cardiocirculatory disease limiting their function. Patients with leg length discrepancies of over 20 mm were excluded because this is expected to significantly impair the walking ability [12]. The patients were all able to walk independently without an assistive device. This study included patients who underwent unilateral THA and those who underwent bilateral THA. For each patient with bilateral THA, the side exhibiting the more pronounced limp was determined by observational gait analysis performed by two physical therapists, 12 and 9 years of experience, respectively.

Patients were randomly assigned to either (1) the “decreased pushoff” group (DP group; n = 12, 7 with unilateral THA and 5 with bilateral THA) or (2) the “increased pushoff” group (IP group; n = 12, 7 with unilateral THA and 5 with bilateral THA). There was no significant difference between the groups regarding patient age, weight, height, body mass index, and

Harris hip score. (Table 1). Patients provided informed consent, and the protocol was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine.

2.2. Exercise interventions

The walking exercises for both groups were prescribed based on the method used by Lewis and Ferris [11]. Instructions were implemented in 2 steps. First, an experienced physical therapist had the patients recognize the shifting the point of pressure on the sole from the heel to the forefoot during walking. Then, each patient was instructed to exert a more or less pressure on the forefeet depending on the group. For the DP group, patients were provided with the instruction to "push less with your foot when you walk." On the other hand, for the IP group, patients were given the instructions to "push more with your foot when you walk." Inevitable changes in motion of the other joints with each walking exercise were allowed. According to individual patient learning levels, each exercise was conducted for approximately 10–15 minutes and included steady walking with the modified walking pattern at least 10 times on a 7-m course in the laboratory. Data were recorded after an experienced physical therapist had confirmed that the patients could walk with the modified walking pattern.

2.3. Gait analysis

Body kinematic measurements were recorded using a 6-camera Vicon motion system (Vicon Nexus; Vicon Motion Systems Ltd. Oxford, England) at a sampling rate of 200 Hz. Reflective markers were attached to the body according to the Vicon Plug-in-Gait marker placement protocol (lower body) by a single investigator. Sixteen markers were placed on both the right and left sides 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.

Three measuring sessions were included in this study. In the pre-exercise session, after the reflective markers had been attached, the patients were instructed to walk on the walkway at least 10 times to familiarize themselves with the environment before the actual trial. The patients were examined while walking at self selected speed. In the second session, walking with conscious changes in the gait patterns were measured after a walking exercise performed for 10–15-min. In the last session, after the walking exercise, the patients were instructed to walk at their natural pace with no conscious changes in their gait patterns while measurements were taken. The specific instructions provided to each patient in this post-exercise session were to “walk naturally without regard to ankle pushoff.” At least three successful trials for each session were recorded for subsequent analysis.

Vicon clinical manager software was used to calculate the basic gait parameters (walking speed and stride length), relative angles between coordinate systems of each segment in the lower limb, and the moment and power in each joint from kinematic data and the ground reaction force. Peak values of joint angle, moment, and power were calculated in the sagittal plane. The joint moments were expressed as internal moments. The powers values were labeled according to the protocol of Eng and Winter [13] (Fig. 1). Additionally, the hip (flexion)/ankle (plantarflexion) moment, hip flexor power absorption (H2)/ankle plantarflexor power absorption (A1), and hip flexor power generation (H3)/ankle plantarflexor power generation (A2) were also calculated. These hip/ankle moment and power ratios characterize the relative moment and relative power of the hip joint to the ankle joint during walking [14]. The values for joint moment (Nm) and power (watts) were normalized with respect to individual's body mass (kilograms). Mean values from three trials for each of the three sessions were used for analysis.

2.4. Statistical analysis

The Statistical Package for Social Sciences 17.0 (SPSS Inc.) was used for statistical analysis. The Shapiro-Wilk test was used to determine whether datasets followed a normal distribution. According to the results of normality, paired *t* tests or Wilcoxon signed-rank tests with Bonferroni corrections were used for comparisons of the 3 sessions in each group.

When significant increases were identified in hip kinematics or kinetics in either group, the relationships between the increasing rate of hip kinematics or kinetics and walking pattern in the pre-exercise session were examined using partial correlation coefficients adjusted for gait speed.

3. Results

Table 2 shows spatiotemporal, kinematic and kinetic variables for both groups for the three sessions. Changes in hip power and hip/ankle power ratio are illustrated in Figure 2. In the pre-exercise session, no significant differences between the groups were observed for any variables. In this study, no significant difference in gait variables between patients with unilateral THA (n = 14) and bilateral THA (n = 10), and no significant correlation between implantation time and any gait variables were found, although there was a range in the implantation time. No patient complained of hip pain in any of the three sessions. Significant differences between pre-exercise and exercise sessions and between pre-exercise and post-exercise sessions in each group are described below.

3.1. Comparison between pre-exercise and exercise sessions

Gait speed was slightly reduced during the exercise session relative to the pre-exercise speed in both groups. In the DP group, the hip extension angle was increased during exercise compared to that during pre-exercise. In addition, a smaller knee flexion angle, greater ankle dorsiflexion angle, and smaller hip extension moment and knee extension moment (early) were identified during exercise relative to the pre-exercise session in the DP group. More importantly, the DP group was found to have a smaller A2 during exercise than during pre-exercise, although hip and knee power remained unchanged (Table 2).

In the IP group, a smaller hip flexion angle, smaller ankle dorsiflexion angle, and marked larger ankle plantarflexion angle were identified during exercise compared to those during pre-exercise. The IP group had a smaller hip/ankle moment ratio in addition to a smaller hip flexion and extension moment during exercise than during pre-exercise, and the knee flexion moment was increased during exercise compared to that during pre-exercise. Although the H3/A2 power ratio was decreased accompanied by the decreased values for H2 and H3 during exercise compared with pre-exercise (Fig. 2), A2 was also decreased during exercise in the IP group (Table 2).

3.2 Comparison between pre-exercise and post-exercise sessions

There was no significant difference between pre-and post-exercise regarding gait speed in the DP group; however, gait speed was slower during post-exercise than during pre-exercise in the IP group (Table 2).

In the DP group, the hip extension angle was increased during post-exercise compared to that during pre-exercise (Table 2). The DP group had a greater H2 value and a greater H2/A1 power ratio during post-exercise than during pre-exercise (Fig. 2). This indicates that the DP group produced greater hip power relative to ankle power in the late stance after the exercise.

In the IP group, the hip flexion angle and knee flexion angle were decreased during post-exercise compared to that during pre-exercise (Table 2). The IP group showed decreased hip flexion moment and decreased hip/ankle moment ratio during post-exercise compared to those during pre-exercise. Moreover, the IP group showed lower H2, H3, and K3 values during post-exercise than during pre-exercise (Table 2, Fig. 2).

3.3. Relationship between the increasing rate of hip power and walking pattern in pre-exercise session

In the DP group, a significant increase in H2 was noted in the post-exercise session compared to that in pre-exercise session. Therefore, the partial correlation coefficients were subsequently computed to examine the relationship between the increasing rate of H2 (−9.8 to 32.1%) and gait parameters in pre-exercise within the DP group. In addition to the inverse correlation between the increasing rate of H2 and the hip flexion moment during pre-exercise, there were also significant positive correlations between the increasing rate of H2 and the ankle dorsiflexion angle, knee extension moment, and A2 in pre-exercise gait (Table 3).

4. Discussion

The results of this study indicated that walking exercise with different ankle pushoff instructions could produce distinct and immediate effects on hip kinematics and kinetics in patients with THA. Walking exercise with decreased pushoff resulted in an immediate increase in H2 and the H2/A1 power ratio in post-exercise session. The changes in the post-exercise session were interpreted as the carrying over effect of the walking exercises. Moreover, this exercise, which increases hip power, was especially effective in patients with greater ankle power generation in their natural gaits. On the other hand, walking exercise with increased pushoff led to decreases in the hip flexion angle, hip flexion moment, and hip flexor power, and as a result, gait speed was reduced in the post-exercise session.

The hip power absorption and generation values observed at pre-exercise in the current study (Table 2 and Fig. 2) were similar to the values reported in a previous study [15], that investigated the gait of patients with hip osteoarthritis (power absorption; −0.76 W/kg: power generation; 1.00 W/kg). Furthermore, these values were lower than those of the age- and size-matched nonclinical individuals (power absorption; −1.17 W/kg: power generation; 1.41 W/kg) in the study [15]. Meanwhile, the ankle power generation values observed during pre-exercise session in the current study (Table 2) were higher than those of healthy individuals (2.66 W/kg) [15]. The gait speeds determined in the present study and the previous study were nearly identical; therefore, the patients in this study would have had less hip muscle power and higher ankle power than nonclinical individuals even in the post-operative stage, in line with previous finding [1,2]. Therefore, it would be necessary to promote the use of hip power rather than ankle power during walking for patients with THA.

According to the comparison of variables between pre-exercise and exercise session, the gait pattern prompted during each walking exercise can be verified. As a whole, exercise with decreased pushoff appears to inhibit ankle pushoff and to facilitate hip motion during exercise. On the other hand, exercise with increased pushoff appeared to inhibit hip function during walking. As the ankle plantarflexion angle was increased in the IP group, the patients in this group appear to be able to focus on altering ankle pushoff. However, as patients with THA would rely on ankle pushoff before exercise, it may be difficult to increase ankle power voluntarily more by walking exercise. It is interesting that instruction to increase ankle pushoff led to an ankle kinematic change rather than a kinetic change. We should note the possibility that walking exercise focusing on increasing ankle pushoff may have the effect of lowering hip function and slowing gait speed in patients with THA.

Walking exercise with decreased ankle pushoff might not only increase the hip power but also shift the power production from the ankle to the hip in the post-exercise session. The plantarflexors eccentrically controlled the forward rotation of the leg over the foot during mid to late single-leg stance, and in phase, uniarticular hip flexors and passive hip structures (e.g. ligaments, tendon, and tissue) are stretched due to hip extension [9,13]. Absorption of energy in ankle plantarflexors and hip flexors including passive structures, contribute to the subsequent return of energy during pre- and initial swing [16]. Ankle plantarflexor and hip flexor strategies would play complementary roles in swing initiation [17]. Indeed, a simulation study has shown that deactivation of the iliopsoas muscle increases the muscle force exerted by the gastrocnemius muscle during gait, and vice versa [18]. In the current study, because of the redistribution of muscle power by the walking exercise with decreased ankle pushoff, patients with THA would produce increased power of the hip flexors relative to the ankle plantarflexors.

As a whole, the IP exercise appeared to more strongly influence post-exercise values than the DP exercise. The most likely reason for this difference is the different effects of the 2 walking exercises on hip function. Inhibition might have been easier than facilitation because hip muscle function was involved to varying degrees in the patients with THA. As facilitation is difficult, the improvement of hip function confirmed in the DP group is noteworthy.

Intervention studies in patients with THA have reported that the walking speed was increased from baseline to post intervention [19–21]; however, treatment-related changes in the gait pattern were not reported. Persistent muscle atrophy, especially in the iliopsoas, has been reported in patients 2 years after THA [10]; thus, it may be more important for patients with THA, to alter the distribution of muscle power during walking to recover hip muscle function than to increase gait speed. The current study provides the first indication that walking exercise with instruction to decrease ankle pushoff can improve the hip kinetics of patients with THA. While this finding was not identified in healthy individuals [11], walking exercise with decreased ankle pushoff might enhance hip power only in the patients who have diminished hip power.

Interestingly, we found that effect of the hip power increase by the walking exercise with decreased pushoff was higher in patients with greater ankle pushoff in their natural gaits. This suggests that patients who have gait patterns with greater ankle pushoff have potential hip power, and these patients have developed gait patterns that excessively compensate for the hip power exertion. These findings provide clinicians with information to select the type of gait pattern that should be applied to walking exercise to rehabilitate patients with THA.

One limitation of our study was that we did not use electromyography. Although we estimated muscle activities by calculating the joint moment and power, changes in the activity of each muscle could have been controlled during the experiment by using electromyography. The current immediate kinematic and kinetic changes induced by walking exercise provide information about the interaction between the hip and ankle joints in patients with THA. Further studies will be necessary to examine the continuous and long-term effects of walking exercise on biomechanics during walking and on hip muscle recovery in patients with THA.

5. Conclusions

Walking exercise with different ankle pushoff instructions has distinct and immediate effects on hip kinematics and kinetics in patients with THA. Walking exercise with decreased pushoff resulted in increased hip power production relative to ankle power. The effect of the hip power increase was higher in the patients with greater ankle pushoff in their natural gaits. Walking exercise with decreased ankle pushoff may help to improve the distribution of muscle power between hip flexors and ankle plantarflexors during walking in patients with THA.

Conflict of interest statement

None of the authors have any conflicts of interest associated with this study.

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Table 1

Anthropometric measurements and Harris hip score for the decreased pushoff and increased pushoff groups

	Decreased pushoff group (n = 12)		Increased pushoff group (n = 12)		*P*-value (non-paired *t* test)
	Mean	(SD)	Mean	(SD)	
Age (y)	59.8	(5.6)	61.8	(5.5)	0.38
Weight (kg)	48.2	(6.2)	53.4	(10.1)	0.74
Height (cm)	154.4	(3.7)	153.7	(5.9)	0.14
Body-mass index	20.2	(2.2)	22.6	(4.3)	0.09
Harris hip score total/100	85.1	(12.2)	92.1	(4.9)	0.11

Table 2

Spatiotemporal, kinematic, and kinetic variables for the decreased pushoff and increased pushoff groups

	Decreased pushoff (DP) group						Increased pushoff (IP) group					
	Pre-exercise		Exercise		Post-exercise		Pre-exercise		Exercise		Post-exercise	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Spatiotemporal parameters												
Speed (m/s)	1.08	(0.10)	0.98	(0.10)†**	1.09	(0.11)‡**	1.15	(0.10)	1.06	(0.12)†*	1.07	(0.11)†**
Stride (m)	1.14	(0.04)	1.14	(0.05)	1.16	(0.05)	1.18	(0.07)	1.18	(0.07)	1.15	(0.05)
Angle (degrees)												
Hip flexion	28.6	(6.0)	27.9	(5.9)	28.3	(5.8)	30.5	(6.2)	27.6	(6.6)†*	28.7	(6.6)†**
Hip extension	−9.4	(6.8)	−10.6	(6.6)†*	−10.1	(7.0)†*	−9.1	(6.6)	−9.8	(6.9)	−9.0	(6.8)
Knee extension	−3.7	(6.1)	−3.7	(5.8)	−3.6	(6.1)	−3.4	(3.5)	−4.7	(3.8)	−3.5	(3.0)
Knee flexion	55.4	(4.3)	50.0	(6.8)†**	54.7	(5.8)‡*	58.2	(6.2)	56.3	(5.3)	56.8	(6.1)†*
Ankle dorsiflexion	18.1	(5.6)	19.9	(5.2)†*	18.6	(5.6)	19.4	(2.3)	14.1	(4.3)†**	18.9	(2.9)‡**
Ankle plantarflexion	19.8	(7.9)	15.9	(9.3)	20.1	(9.9)	17.6	(8.4)	27.5	(10.8)†**	19.9	(8.2)‡*
Moment (Nm/kg)												
Hip extension	0.74	(0.21)	0.59	(0.17)†**	0.73	(0.26)	0.77	(0.16)	0.59	(0.15)†*	0.67	(0.21)
Hip flexion	−0.88	(0.17)	−0.89	(0.18)	−0.91	(0.19)	−0.86	(0.11)	−0.78	(0.13)†**	−0.80	(0.11)†**
Knee extension (early)	0.32	(0.20)	0.23	(0.21)†*	0.33	(0.22)‡**	0.20	(0.15)	0.16	(0.16)	0.15	(0.15)
Knee flexion	−0.04	(0.17)	−0.03	(0.15)	−0.03	(0.15)	−0.08	(0.12)	−0.19	(0.14)†**	−0.10	(0.12)‡**
Knee extension (late)	0.29	(0.08)	0.27	(0.11)	0.31	(0.09)	0.29	(0.11)	0.29	(0.13)	0.30	(0.12)
Ankle dorsiflexion	−0.14	(0.05)	−0.14	(0.04)	−0.14	(0.06)	−0.11	(0.06)	−0.11	(0.06)	−0.11	(0.05)
Ankle plantarflexion	1.21	(0.12)	1.20	(0.13)	1.23	(0.11)	1.26	(0.13)	1.25	(0.14)	1.25	(0.12)
Hip/ankle moment ratio [a]	0.73	(0.11)	0.74	(0.13)	0.75	(0.15)	0.69	(0.12)	0.64	(0.14)†*	0.65	(0.13)†**
Power (W/kg) [b]												
H1	0.54	(0.25)	0.43	(0.18)	0.54	(0.24)	0.64	(0.13)	0.55	(0.27)	0.59	(0.17)
H2	−0.73	(0.20)	−0.73	(0.20)	−0.84	(0.25)†*	−0.84	(0.24)	−0.67	(0.19)†**	−0.69	(0.25)†**
H3	1.05	(0.41)	0.93	(0.41)	1.06	(0.42)	1.21	(0.57)	0.80	(0.42)†**	0.99	(0.53)†*
K1	−0.40	(0.30)	−0.29	(0.26)	−0.51	(0.40)‡*	−0.26	(0.26)	−0.31	(0.29)	−0.21	(0.17)
K2	0.18	(0.12)	0.13	(0.11)	0.21	(0.15)	0.13	(0.09)	0.13	(0.09)	0.10	(0.08)
K3	−1.08	(0.39)	−0.91	(0.44)	−1.10	(0.44)	−1.06	(0.32)	−0.84	(0.33)†*	−0.95	(0.35)†*
A1	−0.95	(0.25)	−0.93	(0.17)	−0.92	(0.25)	−1.07	(0.21)	−1.01	(0.37)	−1.01	(0.12)
A2	4.04	(0.76)	3.48	(0.87)†**	4.15	(0.95)‡**	4.50	(1.14)	3.86	(1.21)†*	4.19	(0.98)
H2/A1 power ratio	0.85	(0.40)	0.83	(0.27)	1.03	(0.45)†*	0.79	(0.20)	0.72	(0.24)	0.71	(0.28)
H3/A2 power ratio	0.26	(0.09)	0.27	(0.09)	0.26	(0.10)	0.27	(0.10)	0.21	(0.08)†**	0.24	(0.12)

[a] Ratio of hip flexor moment to ankle plantarflexor moment

[b] H1, hip extensor power generation; H2, hip flexor power absorption; H3, hip flexor power generation; K1, knee extensor power absorption in the early stance; K2, knee extensor power generation; K3, knee extensor power absorption in the late stance; A1, ankle plantarflexor power absorption; A2, ankle plantarflexor power generation; H2/A1 power ratio, ratio of H2 to A1; H3/A2 power ratio, ratio of H3 to A2.

† Significantly different from the value in the pre-exercise session.

‡ Significantly different from the value in the exercise session.

* $P < 0.0167$

** $P < 0.0033$

Wilcoxon signed-rank tests were used for the following variables because the criteria for normal distribution were not satisfied for the Shapiro-Wilk test:

hip extension angle in the DP and IP groups, hip extension moment in the IP group, knee extension moment (late) in the IP group, H2 in the IP group, K1 in the DP and IP groups, K2 in the DP group, A1 in the DP and IP groups, and H2/A1 power ratio in the DP and IP groups.

Table 3

Partial correlation coefficients between increasing rate of hip power absorption (H2) and kinematic and kinetic variables during the pre-exercise session

		Variables in pre-exercise	*R*-value*	*P*-value
Increasing rate of the H2	vs	Hip flexion moment	−0.72	0.013
		Knee extension moment (late)	0.69	0.018
		Ankle dorsiflexion angle	0.80	0.003
		Ankle power generation (A2)	0.72	0.012

* Partial correlation coefficients adjusted for gait speed

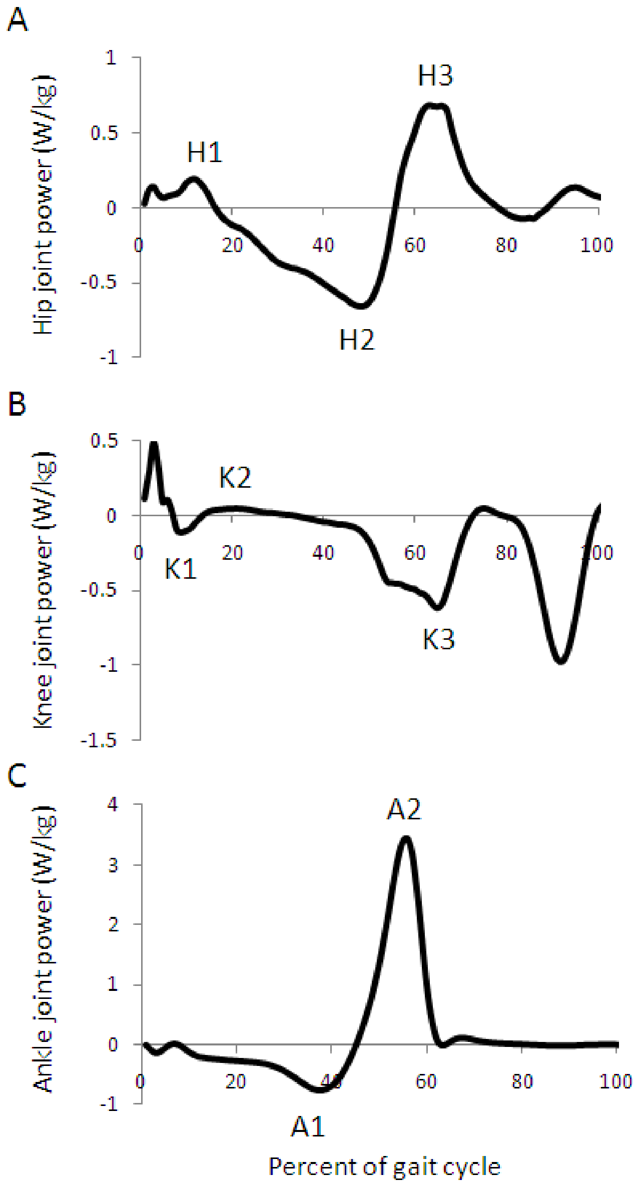
A
Hip joint power (W/kg)
H1
H2
H3
B
Knee joint power (W/kg)
K1
K2
K3
C
Ankle joint power (W/kg)
A1
A2
Percent of gait cycle

Fig. 1.

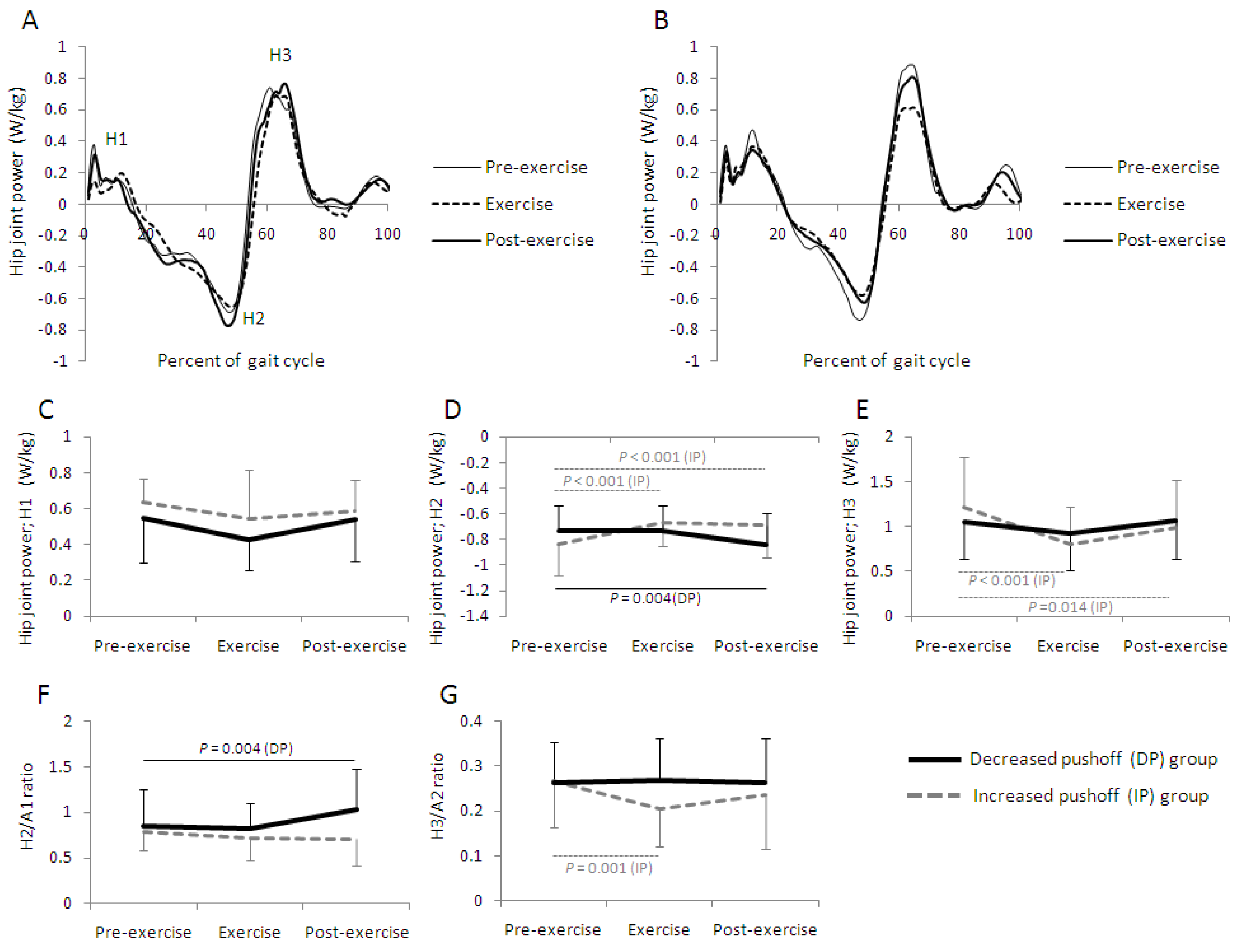
A
H1
H2
H3
Hip joint power (W/kg)
Percent of gait cycle
Pre-exercise
Exercise
Post-exercise
B
C
Hip joint power; H1 (W/kg)
D
Hip joint power; H2 (W/kg)
P < 0.001 (IP)
P < 0.001 (IP)
P = 0.004(DP)
E
Hip joint power; H3 (W/kg)
P < 0.001 (IP)
P =0.014 (IP)
F
H2/A1 ratio
P = 0.004 (DP)
G
H3/A2 ratio
P = 0.001 (IP)
Decreased pushoff (DP) group
Increased pushoff (IP) group

Fig. 2.

FIGURE LEGENDS

Fig. 1.
Joint power normalized to body weight in the sagittal plane across the gait cycle: (A) at the hip, (B) at the knee, and (C) at the ankle joint. The positive values represent power generation. The negative values represent power absorption.

Fig. 2.
Changes in hip joint power and hip/ankle power ratio for the decreased pushoff group (A) and for the increased pushoff group (B) through three sessions. H2 represents hip flexor power absorption, H3 represents hip flexor power generation, A1 represents ankle plantarflexor power absorption, and A2 represents ankle plantarflexor power generation.