Effect of weight-bearing exercise on motor function in female after total hip arthroplasty

（人工股関節置換術後女性の運動機能に対する荷重位エクササイズの効果）

塚越　累

CONTENTS

主論文１

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Stepping exercises improve muscle strength in the early postoperative phase after total hip arthroplasty: a retrospective study

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ABSTRACT

Objective: This study aimed to evaluate the effect of stepping exercises in addition to conventional physical therapy on the recovery of muscle strength and walking speed after total hip arthroplasty.

Design: This was a retrospective study with 6 wks of follow-up care and evaluation. Patients (n = 30) undergoing primary total hip arthroplasty for hip osteoarthritis were divided into two groups based on whether stepping exercises were performed after surgery. The control group (n = 15) received supervised conventional physical therapy for 6 wks. The stepping group (n = 15) performed stepping exercises with conventional physical therapy. Outcome measures were lower limb muscle strength and walking speed at 6 wks postoperatively.

Results: The stepping group showed significantly higher recovery of the hip abductor and the knee extensor muscle strengths on the involved side compared with the control group. There were no significant differences between the two groups in walking speed and hip extensor, hip flexor and knee flexor strength on the involved side.

Conclusions: Our findings suggest that stepping exercises may be effective in facilitating the muscular recovery of the hip abductors and knee extensors in the early postoperative phase after total hip arthroplasty.

Key Words: Total Hip Arthroplasty, Stepping Exercises, Maximal Isometric Strength, Walking Speed

Total hip arthroplasty (THA) is an effective treatment for end-stage hip osteoarthritis. THA relieves pain and reconstructs the hip joint position, which increases the hip abductor moment arm.[1,2] However, functional status, such as lower limb muscle strength and gait capacity, do not adequately improve after surgery. Previous studies have reported that hip muscle weakness,[3,4] gait abnormality,[5-7] reduced walking efficiency,[8,9] impaired postural stability,[10] and motor performance deficit[11] exist after THA. Bertocci et al.[3] and Frost et al.[4] reported that the isokinetic strength of hip abductor, extensor, and flexor and the isometric strength of hip flexor several months after THA were still weak compared with healthy subjects. Although surgical approach would be an important factor affecting recovery after THA, a previous study indicated that the anterior and anterolateral approaches provided similar recovery of isometric hip abductor strength and hip kinematics and kinetics during gait after THA.[12] Furthermore, these measurements were lower at 16 wks after surgery compared with healthy control subjects.[12]

Muscle weakness after THA might partially be caused by surgical invasion of the hip muscles. Minimally invasive surgical techniques are now widely used for THA. These techniques hasten the recovery of muscle strength and functional performance compared with conventional incision because of minimizing soft-tissue dissection such as muscle and tendon.[13,14] However, muscle weakness is still distinct in the early phase after operation, which could partially be caused by the surgical invasiveness. Postoperative physical inactivity, hip pain, and swelling may also decrease muscle activation. Because muscle weakness may lead to motor functional deficits and impairments in activities of daily living, strengthening the hip and knee muscles is a major goal in early rehabilitation after THA.

A few studies investigated high intensity resistance training for postoperative rehabilitation after THA. Suetta et al.[15] indicated that high-intensity knee extension training is more effective in improving muscle strength, the cross-sectional area of the quadriceps muscle, and functional performance than standard rehabilitation or electrical stimulation. Similarly, Husby et al.[16] demonstrated that maximal strength training using leg press and hip abduction exercises improve leg press strength and hip abductor muscle strength more than conventional physical therapy. Although the efficacy of high-intensity and low-frequency strength training has been confirmed by these studies, that of low-intensity and high-frequency weight-bearing training for muscle recovery after THA was not examined.

Stepping machine exercises involve rhythmically bending and extending the bilateral hip and knee joints. These exercises have been used to improve lower limb strength and aerobic capacity in knee rehabilitation[17,18] and cardiovascular fitness.[19,20] Mean muscular activity of the hip and knee muscles during stepping exercises ranged from 10% to 40% of maximum voluntary isometric contraction in healthy subjects. Maximal flexion angle of the knee joint during this exercise was about 50 degrees.[21,22] Therefore, stepping exercises should be safe and convenient to use for rehabilitation after lower limb joint surgery. More than 60% of one repetition maximum was necessary to increase the cross-sectional area of a muscle in healthy individuals.[23] Although the intensity of the stepping exercises might be insufficient for healthy individuals to increase muscle strength, we hypothesized that this low-intensity and high-frequency training would be suitable for patients who are early postoperative.

The weight bearing on the surgical leg is insufficient during daily activities, such as walking and standing, in the early phase after THA because of hip pain, fear of loading, and muscle weakness.[11,24] This reluctance to load the leg inhibits muscular activity and may delay muscle recovery after surgery. Stepping exercises are expected to facilitate weight bearing on the affected limb and increase muscle activity because the repeated step motion causes the center of mass to shift bilaterally while in the standing position. In June 2006, we introduced the stepping exercises into our rehabilitation program after THA surgery. However, we have not found any previous research that investigates whether stepping exercises are effective in patients undergoing THA.

The purpose of this study was to retrospectively investigate how stepping exercises in the early THA postoperative phase would influence the recovery of muscle strength and gait. We hypothesized that the group who performed the stepping exercises in addition to conventional physical therapy would significantly improve lower limb muscle strength and gait ability, compared with the group who were treated using conventional physical therapy only.

METHODS

Study Design and Subjects

We conducted a retrospective study of THA patients who underwent THA surgery at Rakuyo

Hospital, Kyoto, Japan. A total of 201 women who received a primary unilateral THA for hip osteoarthritis in Rakuyo Hospital between June 2004 and August 2007 were enrolled in this retrospective study according to medical charts (Fig. 1). A total of 82 of the 201 patients were excluded because of revision THA, using a combination of bone graft or femoral osteotomy. All 119 remaining patients received diagnoses of osteoarthritis as the main cause for THA and underwent anterolateral approach in THA surgery. A total of 89 of these 119 patients were excluded because they did not complete all the testing procedures. Eventually, a total of 30 patients were enrolled. Because stepping exercises were introduced into postoperative rehabilitation in June 2006, 15 of these patients who received THA surgery before May 2006 were allocated to the control group that performed conventional physical therapy only. The remaining 15 subjects who received surgery after June 2006 were assigned to the stepping group that performed stepping exercises in addition to conventional physical therapy.

One orthopedic surgeon (H. Okumura), who had performed more than 2000 THA procedures, performed all the THA surgeries. The anterolateral approach was performed as described by Mostardi et al.,[25] and the length of the skin incision was 10 to 12 cm. During the surgical procedure, gluteus medius muscle, gluteus minimus muscle, and tensor fasciae lata were partially incised. The cementless acetabular and femoral implants were used (Trilogy Acetabular System & Versys Hip System; Zimmer, Warsaw, IN or K-MAX ABC Hip System; Kobelco, Kobe, Japan).

Before conducting this retrospective study, oral informed consent for participation was obtained from all patients. This study was approved by the ethical board of Kyoto University Graduate School of Medicine.

Assessments

Information regarding age, weight, height, body mass index, and preoperative Japanese Orthopaedic Association hip score[26] were obtained from medical charts to evaluate the anthropometric characteristics of the subjects.

Isometric strength of the lower limb and walking speed both before surgery and 6 wks postoperatively were obtained from the medical charts to evaluate the effects of the stepping exercises. These variables were measured according to the testing procedures described in the next section. In addition, we investigated whether there were any reports of adverse events from the stepping exercises.

Testing Procedures

All of the patients were evaluated 2 days before and 6 wks after surgery. At the beginning of each testing session, the patients performed 5 mins of walking at a comfortable speed or 5 mins of exercise on a stationary ergometer with an intensity of 0.5 kg. All testing sessions were performed in the same order.

Maximal Isometric Strength of the Lower Limb

The strength of bilateral hip abductors, hip extensors, hip flexors, knee extensors, and knee flexors were measured using a handheld dynamometer (MEDIX, Tokyo, Japan). Good interrater and test-retest reliability of handheld dynamometer measurements have been verified in previous studies of older,[27] hip fracture,[28] and THA[10,29] patients. Strength tests were performed in the following order in each lower limb: hip abductors, hip extensors, hip flexors, knee extensors, and knee flexors. These measurements were assessed by a single examiner with 7 yrs of clinical experience who was not blinded to group allocation. The position of the patient for each muscle test was as follows: hip abductors, supine with neutral hip adduction/abduction; hip extensors, prone with neutral hip flexion/extension; hip flexors, knee extensors, and knee flexors, seated on a platform with 90 degrees of hip and knee flexion, leg perpendicular to the floor, and feet off the floor. To stabilize the body and minimize muscle compensation, the examiner fixed the pelvis during hip extension and the contralateral thigh during hip abduction testing. Similarly, the participants held the edge of platform during testing of the hip flexors, knee extensors, and knee flexors.

The sensor pads of the handheld dynamometer were placed on the lateral, posterior, and anterior thigh just proximal to the knee joint for the hip abductors, extensors, and flexors. The pads were positioned on the anterior and posterior leg just proximal to the ankle joint for the knee extensors and flexors. The length (in meters) of the lever arms were measured from the estimated center of rotation of the joint to the center of the sensor pad. In each testing condition, a make test was used because a make test has been shown to be more reliable than a break test.[30,31] Isometric muscle strengths were measured twice for 3 secs after three practice trials, and mean values were obtained. Verbal encouragement was given during the test. Participants were given a brief rest (30 secs) between consecutive contractions and at least 1 min of rest between the tests of each muscle group. Each strength value (in newtons) and lever arm (in meters) was converted into a ratio of torque to body weight (in newton-meters per kilogram).

In the present study, the test-retest reliability of the handheld dynamometer was estimated by calculating the intraclass correlation coefficients (1,1) for all measurements in seven healthy women. The intraclass correlation coefficients (1,1) was 0.917 for the hip abductors, 0.935 for the hip extensors, 0.915 for the hip flexors, 0.902 for the knee extensors, and 0.945 for the knee flexors. They were considered excellent.

Walking Tests

Comfortable and maximal gait speeds were measured before and 6 wks after surgery on a 10-m unobstructed path using a digital stopwatch. If needed, the patients used a cane. The 10-m walking test was chosen because it could be easily and safely measured soon after surgery and is frequently used as a clinical outcome measure. Participants were provided with several meters to accelerate and decelerate before and after the test distance. For the comfortable speed walking trials, they were instructed to walk at their preferred speed. For the maximal speed walking trials, they were asked to walk as fast as they were safely able to without running. These walking speeds were measured twice, and the mean values were used for analysis. No encouragement was given during the tests.

Postoperative Rehabilitation

All subjects received conventional physical therapy treatment in a rehabilitation unit from the third day after surgery. Sessions lasted 1 hr a day and were performed 6 days a week for 6 wks. Conventional physical therapy consisted of joint range of motion, muscle strength exercises, and functional exercises. Exercises to increase the range of motion of the hip joint consisted of passive flexion, extension, abduction, and external rotation performed manually by the physical therapist. Muscle strength exercises were single joint exercises in hip abduction/adduction, hip flexion/extension, and knee flexion/extension. Initially, active assisted and then active exercises without resistance were used. Later, exercises against progressive resistance were introduced. Exercise resistance was applied manually by the physical therapist. For the hip abductors, resistance was applied by a Thera-band fixed to the ankle or knee with the patient in a supine position. For the hip flexors and knee extensors, resistance consisted of a sandbag fixed to the ankle with the patient in a seated position. Each exercise was repeated 10 to 50 times, according to patient’s fatigue or muscle pain. Gait training started from the fifth day after surgery using a parallel bar. Thereafter, assistive devices such as a walker, crutch or cane were used. The walking distance on a level surface was increased gradually, and then stair climbing was added. Calf raise exercises and squatting and single leg-standing exercises were also performed to increase muscle strength and improve capacity of balance. Cycling exercises using the stationary ergometer were performed 2 to 3 wks after surgery. The load during the cycling exercises was 25 to 60 W, and the duration was 10 to 15 mins.

The subjects in the stepping group performed stepping exercises using a machine (Fighting Load, Tokyo, Japan; Fig. 2) in addition to the conventional physical therapy. Stepping exercises were performed for 50 repetitions starting 1 wk after surgery. Fifty repetitions were added each week, with up to 250 repetitions at 5 wks postoperatively. The stepping rate was about 60 steps per minute, so 1 to 5 minutes were required to perform these exercises. The range of step inclination was 0 to 30 degrees, and the step load was adjustable by changing the angle of inclination. At the beginning of the exercises, step inclination was lowered if patients could not perform the exercises at maximal inclination. Handle bars were available in front of the stepping machine, but the participants were encouraged to perform the exercises without them.

Statistical Analysis

Data is expressed as mean ± SD. As the normal distribution of the all variables was confirmed using the Shapiro-Wilk test, parametric analysis was performed. Before surgery, the anthropometric variables for the two groups were compared using the unpaired *t* test. Analysis of variance with repeated measures (group [stepping *vs.* control] × time [before surgery *vs.* 6 wks after]) was used for the lower limb muscle strength and walking speed. The level of significance was set at $P < 0.05$. We used the software program SPSS (version 17.0, Tokyo, Japan) for statistical analysis.

In rehabilitation research, clinical importance has been defined as a clinical improvement of 15% or more, relative to a control group.[32] Therefore, when a significant interaction was observed, the relative differences between the stepping group and the control group were calculated using the following equation:

$$\text{Relative difference} = [(\Delta S - \Delta C) / All_{base}] \times 100\%$$

where ΔS and ΔC are the mean within-group changes from baseline of the stepping group and the control group, respectively, and All_{base} is the mean value of the baseline measures of the two groups.[33]

RESULTS

Participants

According to the evaluation by medical charts, a total of 30 of 201 patients were enrolled in the study. Of these, 15 subjects performed the stepping exercises in addition to the conventional physical therapy and were allocated to the stepping group. The remaining 15 subjects were assigned to the control group. There were no reports of adverse effects caused by the stepping exercises in the medical chart.

The anthropometric data for the two groups are given in Table 1. There were no significant differences between the two groups in age, mass, height, body mass index, and Japanese Orthopaedic Association hip score before surgery.

Muscle Strength Measurements

Table 2 lists the results of the muscle strength tests. Analysis of variance showed a significant group × time interaction effect in hip abductor and knee extensor strength in the involved limb, with the stepping group showing a significantly higher recovery than the control group ($P < 0.05$). The relative differences of the involved hip abductor and knee extensor muscles between the two groups were 17% and 19%, respectively. Therefore, a clinically important difference may exist in these muscle strengths. There were no group × time interaction effects in the involved hip extensor, hip flexor and knee flexor and in the strength of all the muscles on the uninvolved limb between the two groups.

Walking Tests

Comfortable and maximal walking speeds before and 6 wks after surgery are shown in Table 3. Neither comfortable nor maximal walking speed showed significant interaction effects between the two groups.

DISCUSSION

To facilitate the muscle strength recovery of the lower limb after THA surgery, muscle activation is effectively improved by promoting weight bearing on the involved leg during the early postoperative phase. Stepping exercises were expected to promote loading of the surgical leg through the repeating step motion. In this study, stepping exercises were introduced for postoperative rehabilitation, and the training effects were validated. Stepping exercises can be performed easily and safely, and no reports of adverse effects were noted in the stepping group performing exercises.

This study revealed that stepping exercises were effective for the recovery of the hip abductor and knee extensor muscles on the involved side. The stepping group showed a significantly higher recovery than did the control group according to repeated-measure analysis of variance. However, this study has the potential of making a type I error because of multiple comparisons; we calculated the relative difference when evaluating the clinical implications. The relative difference in the recovery of these muscles was more than 15% between the intervention group and the control group. This indicates that the addition of stepping exercises to conventional physical therapy has clinically important benefits compared with conventional physical therapy only.

Hip abductor weakness is considered one of the causes of gait abnormality, such as Trendelenburg or Duchenne sign, and loosening or dislocation of the prosthesis.[34,35] The knee extensor strength is also related to the ability to perform activities of daily living, such as standing up from a chair and stair climbing.[36,37] According to previous studies assessing muscle atrophy in patients with hip osteoarthritis, the atrophy of the gluteus medius[38] and the quadriceps[39] muscles are particularly notable and persist for at least 6 mos after surgery.[40] The stepping exercises performed in this study effectively improved the function of these two muscles after THA surgery.

Stepping movements consist of the hip and knee extension phase and the hip and knee flexion phase. Previous studies indicated that the activation of the quadriceps was higher than 40% of maximal voluntary contraction in the extension phase, whereas the activation of the hamstrings was lower than 10% of maximal voluntary contraction in both the extension and flexion phases in healthy subjects.[21,22] Moreover, because bilateral perturbation of the center of mass was induced by the stepping motion, gluteus medius muscle activation would be enhanced to control the mediolateral stability of the hip. Better improvement of the hip abductor and knee extensor muscles compared with the hip flexor and knee flexor muscles in the involved limb in the intervention group could be caused by this characteristic of stepping exercises. According to the principle of training specificity, multijoint weight-bearing training, such as squatting and stair stepping, appears to be unsuitable in improving single joint muscle strength measured in a non-weight-bearing position. Reynolds et al.[41] reported that the lateral step-up training, which is similar to the stepping exercises used in the current study, performed by healthy subjects for 6 wks, did not change the isokinetic strength of the knee extensors. Similarly, Worrell et al.[42] reported that step training did not improve isokinetic knee extension strength in healthy subjects. The training specificity and overload principles of muscle training may explain the inadequate effect on muscle strength gain in these previous studies. Exercise intensity of at least 60% of maximal voluntary contraction is necessary to improve muscle strength, so the intensity of the lateral step-up exercise is too low for healthy subjects. However, the subjects who participated in this study were patients in early postoperative phase after THA whose muscle force production was inhibited by surgical invasion, immobilization and hip pain. It was thought that low-intensity training like the stepping exercises was sufficient in improving muscle strength in these patients, according to the overload principle.

In previous studies, Husby et al.[16] reported that maximal strength training intervention caused hip abduction to increase 150% and leg press to increase 93% relative to preoperative strength on the involved side 5 wks after THA surgery. Suetta et al.[43] also demonstrated that resistance training intervention improved knee extension strength by approximately 106% relative to preoperative strength at 5 wks postoperatively. In the present study, hip abduction and knee extension strength recovered to 128% and 102%, respectively, 6 wks after surgery. The extent of muscle strength gain from the intervention in the present study is comparable with that of other clinical trials. Although intervention was initiated on a similar time frame in these previous studies, two major dissimilarities were training intensity and frequency. Husby et al.[16] used an intensity of 85% of one repetition maximum and frequency of 20 repetitions, whereas Suetta et al.[43] applied the 50% to 80% of one repetition maximum and 30 to 50 repetitions for resistance training. In the present study, the stepping exercises were of lower intensity and higher frequency compared with both previous studies. Because massive strength training increases the risk of muscle soreness and hip pain in the early postoperative phase, low-intensity and high-frequency training could be more safety performed. However, to investigate whether low-intensity and high-frequency training is a better intervention than training with a high load and few repetitions, a randomized controlled trial comparing these two types of training is necessary.

The results of the walking tests did not indicate the efficacy of this intervention for walking ability. Because the stepping exercises were performed in a standing posture and did not require a large range of hip joint motion, they would have little effect on gait factors such as stride length and step frequency. It has been reported that resistance training[15] and low-frequency electrical muscle stimulation intervention[44] for the quadriceps do not improve walking speed compared with standard rehabilitation at 35 and 45 days after THA. Moreover, maximal strength training for THA patients did not improve gait patterns such as step length and stance time after 12 wks of intervention.[16]

Although the only functional assessment in this study was walking speed, differences in gait function between the intervention and control groups might have been revealed more in a 6-min walk test, where the hip abductor muscle strength would be more challenged[45]. In exercises of short duration such as 10-m walking speed test, it is possible that low abductor muscle strength may be masked. In addition, monitoring activity level for 1 wk could have contributed valuable information on the functional impact of stronger lower limb muscles. Further studies are warranted to examine the effects of stepping exercises on other measures of functional status.

A severe limitation of this study is that the study design was not a randomized controlled trial but a retrospective study. A randomized controlled trial is a better design to evaluate the clinical efficacy of an intervention. In the present study, because the subjects in the control group and stepping group were selected from early and later periods, respectively, it is conceivable that the results could have been influenced by other causes that might have changed over time. However, the operation method and rehabilitation protocol were identical for both periods as described in “Method,” and therefore any such changes could only be minimal. In addition, because the study period was continuous and relatively short, we assume that there were no major changes of medical, nursing, or other care that could have influenced the outcomes of this study. Of 119 patients who received primary THA without bone grafts, 30 patients who completed all the gait tests and the muscle strength tests were included in this study. Therefore, the effect of stepping exercises in those who did not fulfill these tests is not clear. There is a possibility that those who did not undergo these tests could not perform them because of low activity level or pain. The results of this study could be generalized only to those who have relatively high activity level and in whom recovery after operation was favorable. Because all subjects in this study were women who underwent primary THA for hip osteoarthritis and were non-obese patients and could bear weight postoperatively, it is difficult to generalize the efficacy of stepping exercises to men, those who have undergone revision THA, obese patients, and patients with restricted weight bearing after THA. The subjects in this study were hospitalized for a longer period and received more physical therapy compared with typical US patients. It is therefore possible that subjects in both groups recovered more in muscle strength and walking speed compared with patients who are hospitalized for shorter periods.

This retrospective study showed that stepping exercises were an effective intervention after THA surgery. The patients who performed stepping exercises in the early postoperative phase after

THA showed higher recovery of hip abductor and knee extensor muscle strengths than the patients who received only conventional physical therapy. However, stepping exercises did not show positive effects on comfortable and maximal walking speeds.

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DISCLOSURES

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Table 1: Preoperative anthropometric data for the two groups

	Stepping (mean ± SD)	Control (mean ± SD)	*P*
n	15	15	
Age, yrs	59.5 ± 5.9	59.3 ± 9.5	0.95
Height, cm	152.3 ± 4.0	152.4 ± 3.4	0.92
Weight, kg	52.5 ± 3.0	54.2 ± 7.3	0.41
BMI, kg/m^2	22.7 ± 1.5	23.4 ± 3.2	0.46
JOA hip score (0-100)	51.1 ± 6.0	51.5 ± 5.8	0.84

P values represent the probability for differences between the two groups as evaluated using an unpaired *t* test. BMI, body mass index; JOA, Japan Orthopaedic Association.

Table 2: Muscle strength measurements for the two groups

		Stepping group (n = 15)		Control group (n = 15)		
		Preoperative (mean ± SD)	6 Wks (mean ± SD)	Preoperative (mean ± SD)	6 Wks (mean ± SD)	*P*
Involved	Hip Abductor, Nm/kg	0.75 ± 0.18	0.93 ± 0.19	0.80 ± 0.19	0.85 ± 0.21	0.04
	Hip Extensor	0.60 ± 0.19	0.73 ± 0.14	0.63 ± 0.19	0.67 ± 0.19	0.16
	Hip Flexor	0.65 ± 0.14	0.74 ± 0.12	0.65 ± 0.17	0.69 ±0.19	0.43
	Knee Extensor	0.93 ± 0.21	0.92 ± 0.10	1.05 ± 0.25	0.85 ±0.21	0.02
	Knee Flexor	0.57 ± 0.14	0.63 ± 0.11	0.58 ± 0.14	0.63 ±0.10	0.68
Uninvolved	Hip Abductor, Nm/kg	0.89 ± 0.22	0.97 ± 0.17	0.90 ± 0.22	0.97 ± 0.28	0.90
	Hip Extensor	0.78 ± 0.22	0.83 ± 0.20	0.87 ± 0.24	0.87 ± 0.32	0.47
	Hip Flexor	0.90 ± 0.20	0.94 ± 0.18	0.88 ± 0.18	0.98 ± 0.26	0.25
	Knee Extensor	1.22 ± 0.22	1.28 ± 0.18	1.32 ± 0.30	1.34 ± 0.28	0.63
	Knee Flexor	0.64 ± 0.14	0.70 ± 0.13	0.63 ± 0.14	0.67 ± 0.10	0.61

P values represent the probability for interaction effect (group × time) as computed using a repeated-measures analysis of variance.

Table 3: Walking speeds for the two groups

	Stepping group (n = 15)		Control group (n = 15)		
	Preoperative (mean ± SD)	6 Wks (mean ± SD)	Preoperative (mean ± SD)	6 Wks (mean ± SD)	*P*
Comfortable walking speed, m/min	53.6 ± 11.2	55.3 ± 10.2	55.0 ± 13.9	51.6 ± 10.9	0.30
Maximal walking speed, m/min	72.9 ± 16.9	69.8 ± 10.2	74.5 ± 17.8	68.4 ± 14.3	0.56

P values represent the probability for interaction effect (group × time) by a repeated-measures analysis of variance.

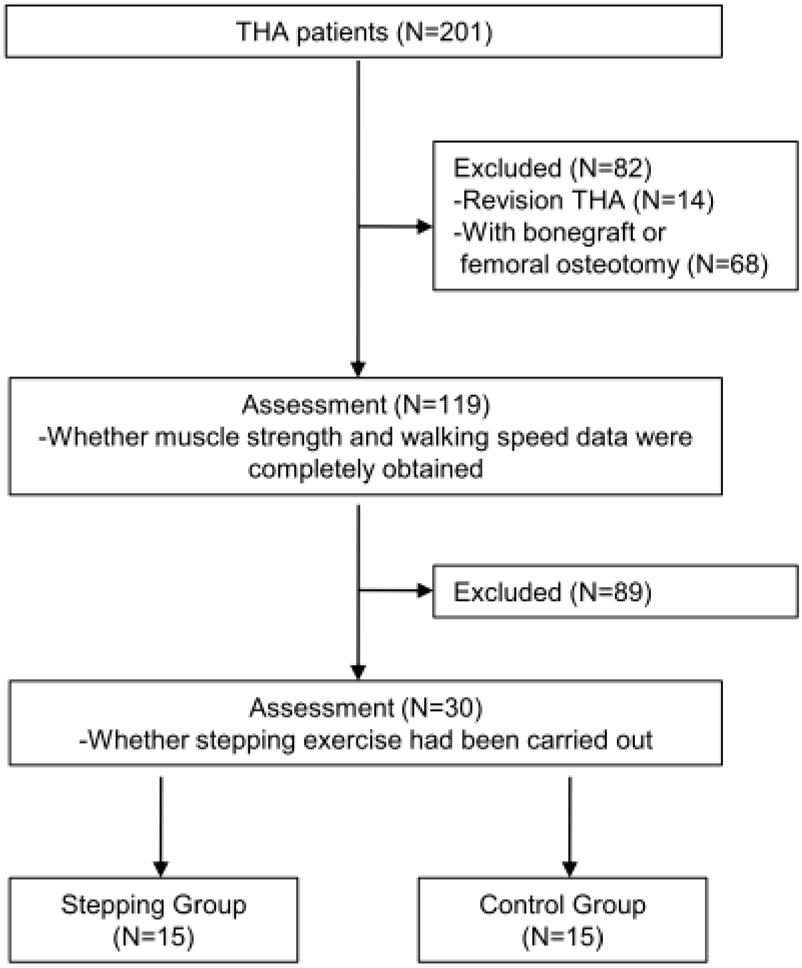

Figure 1. Flow diagram of the study subjects.

Figure 2. Stepping exercise during training. The step boards slide alternately from 0 to 30 degrees, whereas the number of steps taken is digitally displayed.

主論文 2

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Functional performance of female patients more than 6 months after total hip arthroplasty shows greater improvement with weight-bearing exercise than with non-weight-bearing exercise. Randomized controlled trial

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ABSTRACT

Background. Impaired functional performance and decreased muscle strength and muscle atrophy generally persist for a long period after total hip arthroplasty (THA).

Aim. To investigate the effects of weight-bearing (WB) and non-weight-bearing (NWB) exercises on functional performance, Harris hip score (HHS), muscle strength and muscle thickness in women after THA.

Design. A randomised, controlled trial.

Setting. Community.

Population. Sixty-five women who had undergone unilateral or bilateral THA at least 6 months before enrolment in the study.

Methods. Participants were randomly allocated to the following groups: WB (n = 22), NWB (n = 21) and control (n = 22) groups. Participants in the WB and NWB groups performed daily home exercise programs for 8 weeks. Functional performance (timed up and go, sit-to-stand, stair climbing, walking speed and 3-min walk test), HHS, isometric muscle strength of the hip and knee muscle and gluteus and quadriceps muscle thickness were measured at baseline and after 8 weeks.

Results. An intention-to-treat analysis revealed that both the intervention groups exhibited significant improvements in almost all functional performance measures compared with the control group. Furthermore, the WB group showed significantly greater pre–post changes in the sit-to-stand and 3-min walk test compared with the NWB group. In terms of HHS, only the WB group showed significantly greater improvement compared with the control group. Relative to the control group, improvements in all isometric strength measures were observed in both the intervention groups. Significant improvement in quadriceps muscle thickness was observed in the WB group compared with the control group. However, no significant difference was observed among the three groups in pre–post changes in gluteus muscle thickness.

Conclusion. WB and NWB home exercise programs were both effective for improving functional performance and muscle strength in women after THA. However, the WB exercise was more effective than the NWB exercise for improving sit-to-stand ability and walking endurance.

Clinical rehabilitation impact. In this study, we demonstrated that the WB exercise was more effective than the NWB exercise for improving functional performance in patients after THA.

Key Words: Arthroplasty, Exercise, Functional performance, Muscle strength

Total hip arthroplasty (THA) is a widely used surgical approach for severe hip osteoarthritis. Although THA is very effective for pain relief, adjustment of leg length discrepancy, and increased hip range of motion,[1, 2] decreased muscle strength and impaired functional performance persist for a long period after surgery. Several studies have demonstrated that patients with THA have substantial loss of hip and knee muscle strength on the affected side compared with the healthy side and with normal individuals.[3-6] Rasch et al. also reported decreased cross-sectional area and increased fat infiltration as measured by radiological density of the hip muscle in patients 2 years after THA and suggested that there is persistent hip muscle atrophy after THA.[7] Because weakness of the hip musculature is a risk factor for joint instability and dislocation,[8-10] in addition to deficits in functional performance, increasing muscle strength is a critical issue in postoperative rehabilitation. With regard to functional performance deficits, previous studies have indicated reduced gait ability,[11-13] postural stability,[14-16] stair ascending or descending ability,[17, 18] and sit-to-stand ability. [19, 20]

Rehabilitation is performed at the hospital immediately after THA surgery, and many patients receive outpatient or home health physical therapy for several weeks after discharge.[21-23] Because the above mentioned physical impairments persist, researchers have advocated a continuing post-THA exercise program consisting of muscle strengthening and active range-of-motion exercises. Previous studies have demonstrated that several weeks of exercise programs including strength, postural stability, or walking exercises significantly improved muscle strength, postural stability, and functional scores in the late postoperative phase.[24-27] In general, patients with THA are prescribed a combination of non-weight-bearing (NWB) exercises, such as hip abduction and knee extension, and weight-bearing (WB) exercises, such as one-leg standing and squatting. A recent systematic review indicated that despite WB exercise possibly being effective in improving the motor function of patients with THA, there have been few studies that have rigorously compared the efficacy of WB and NWB exercises.[28 29] The present study aimed to investigate the effects of WB and NWB exercises on functional performance, disease-specific functional outcome measure, muscle strength, and muscle thickness in patients with THA. We hypothesized that WB exercise would be superior to NWB exercise for improving both functional performance and muscle strength.

Materials and methods

Participants

Participants were recruited from August 2010 to September 2011 through two hospitals in Kyoto, Japan. Women who had undergone primary THA for hip osteoarthritis were screened by four orthopedic surgeons according to the following inclusion and exclusion criteria when visiting hospitals for periodic check-ups after THA. Inclusion criteria for this study were as follows: 1) ability to walk unaided at least 50 m; 2) greater than 6 months and less than a decade since THA surgery; and 3) below the age of 75 years. Exclusion criteria were as follows: 1) hip revision surgery; 2) infection; 3) loosening of the femoral or acetabular component; 4) central or peripheral nervous system involvement; 5) an additional musculoskeletal disorder affecting walking; and 6) cognitive problems.

Sixty-five women who met the criteria participated in this study. Their average age was 62.7 ± 6.8 years (range 49–75 years). For subjects who underwent bilateral THA, the side exhibiting the more pronounced limp was determined by observational gait analysis performed by three physical therapists. All three physical therapists agreed on the side to be assessed for all subjects with bilateral THA. THA surgery in all the subjects was performed using the anterolateral approach, and there were no restrictions on weight bearing after surgery. All subjects received physical therapy in a rehabilitation unit after surgery for 4–6 weeks. Physical therapy consisted of hip joint range of motion, lower extremity muscle strength exercises, and functional exercises such as walking, standing up from a chair, and stair climbing.

Before being included in the study, subjects gave their informed written consent to participate. Participants were then randomly allocated to the WB (n = 22), NWB (n = 21), or control (n = 22) groups. Block randomization (six participants per block) was carried out using a computer-generated random number sequence by Excel (Microsoft, Redmond, WA, USA) (Figure 1). This study was approved by the Ethical Board of Kyoto University, Graduate School of Medicine.

Outcome Measures

Assessments were performed at the baseline and within 1 week following the 8-week intervention or 8-week control. The two physical therapists who performed the assessments were not blind to group allocations. Functional performance was evaluated as the main outcome measure of the present study, and Harris hip score (HHS), isometric strength, and muscle thickness were also assessed as secondary outcome measures.

Functional Performance

The sit-to-stand (STS), timed up and go (TUG), stair climbing test (SCT), maximal walking speed (MWS) and 3-min walk test (3MWT) were measures of functional performance. The STS test measured the time taken to complete five repetitions of the STS maneuver using a straight-backed chair (43 cm high, 45 cm deep) without an arm rest. Participants were instructed to fold their arms across their chest and to stand up and sit down five times. High test-retest reliability has been established in osteoarthritis patients.[30] The TUG test was performed using the abovementioned chair. Participants were asked to stand up from the chair, walk 3 m, turn around, return to the chair and sit down. This test has high test-retest reliability.[31] The SCT required participants to ascend 10 stairs (step height, 17.5 cm). Previous studies have reported high test-retest reliability for this measurement in patients with hip osteoarthritis and patients undergoing THA.[30, 32] The MWS was measured on a 10-m unobstructed path. Participants were given several meters to accelerate and decelerate before and after the test distance. Test-retest reliability has been confirmed in previous studies.[32, 33] Participants were instructed to perform the each task as fast and safely as possible, and the time was measured with a stopwatch. After two practice trials, each task was measured twice, and the faster values were used for analysis. During the measurement of the 3MWT, participants were instructed to cover as much distance as possible during the 3-min time frame in a flat indoor corridor with a 25-m marked track and cones as turning points. Time was measured with a stopwatch and called out every 30 s. The total distance walked was recorded to the nearest meter. The reliability of the measurement of 3MWT was assessed in a pilot study. Ten women with THA (mean age 64.3 years; SD 5.9) were recruited for the reliability analysis. The intraclass correlation coefficient (ICC) and the standard error of measurement (SEM) were calculated, and high test-retest reliability was confirmed (ICC = 0.95, SEM = 9.14 m).

Harris Hip Score

Disease-specific functional outcome measure was performed using a HHS range of 0-100, with 100 indicating the highest level of function. This score includes assessment of pain, function, activities of daily living, and deformity and range of motion of the affected joint. The high validity and reliability of this score system has been confirmed in previous study.[34]

Isometric Strength

Strengths of the hip abductor, extensor, and flexor of the affected limb were measured using a hand-held dynamometer (HHD; μTas F-1; Anima Corp., Tokyo, Japan). Good inter-rater and test-retest reliability of HHD measurements have been verified in previous studies on THA patients.[16, 35] Knee extensor strength was measured using an electromechanical dynamometer (ISOFORCE GT-330; OG giken Co. Ltd., Tokyo, Japan). Strength tests were performed in the following order and positions: hip abductor, supine with neutral hip adduction/abduction; hip extensor, prone with neutral hip flexion/extension; hip flexor, seated on a platform with 90° hip and knee flexion, leg perpendicular to the floor, and foot off the floor; knee extensor, seated on an ISOFORCE with the hip flexed to 90° and the knee flexed to 60°. The sensor pads of the HHD were placed on the lateral, posterior, and anterior thigh just proximal to the knee joint for measuring hip abduction, extension, and flexion. The distal edge of the shin attachment of the ISOFORCE was placed 5 cm proximal to the lateral malleolus of the test leg for the knee extensor measurement. The lengths (m) of the lever arms were measured from the estimated center of rotation of the hip and knee joints to the center of the sensor pad of the HHD and shin attachment of ISOFORCE, respectively. The strengths were measured twice for 3 s after three practice trials, and the higher values were used. Verbal encouragement was provided during testing. Each strength value (N) and lever arm (m) was converted to a torque/body weight ratio (Nm/kg).

Muscle Thickness

Sagittal ultrasound images were obtained using a B-mode ultrasound imaging device (LOGIQ e; GE Healthcare UK Ltd., Chalfont, Buckinghamshire, UK) with an 8-MHz linear-array probe. Four muscles in the lower limbs, the gluteus maximus, gluteus medius, gluteus minimus, and quadriceps were examined as described in a previous study.[36] The thickness of the quadriceps is the sum of the vastus lateralis and vastus intermedialis muscles. The same standardized subject position and exact location of the probe were carefully maintained throughout the examination. To improve acoustic coupling, a water-soluble transmission gel was placed over the scan head. The probe was held perpendicular to the skin surface using the minimum pressure required to achieve a clear image. The thickness of each muscle was measured using an electronic caliper on frozen images, as previously described. All measurements were performed once by the same investigator. The reliability of the ultrasound technique for measuring thicknesses of these four muscles has been demonstrated in previous studies.[36, 37]

Interventions

After baseline measurements, a physical therapist individually instructed the participants in the 8-week daily WB or NWB home exercise programs.

The six WB exercises were half squats, STS from a chair, opposite-side pelvic raises, pelvic rotations, hip extensions in gait posture, and tandem gait (Figure 2). The exercise volumes were three sets of 15 repetitions/set for squats, STS, unilateral pelvic raises, and hip extensions, and three sets of 2 min/set for lumber rotations and tandem gait. Subjects were instructed to move slowly and maintain good form.

The six NWB exercises were supine straight leg raises and bridging, side-lying hip abduction, prone hip extension, and sitting knee extension and flexion using a Thera-band (Hygenic Co., Akron, OH, USA) (Figure 3). Three sets of each exercise were performed with 15 repetitions/set. Subjects were instructed to move slowly and hold each position for 3 s.

Participants in both exercise groups were provided with material depicting good examples of the exercises. They were asked to complete the program daily and record the number of repetitions completed on an exercise log. The physical therapist contacted the participants every 2 weeks by telephone and modified the number of repetitions as necessary. Both exercise programs required approximately 30 min to complete. The compliance rate was deemed as 100% if the participant had completed a total of 56 days of exercise over 8 weeks.

The participants of the control group were instructed to maintain their lifestyle for the duration of this study.

Statistical Analysis

Basic subject information and baseline values for functional performance, HHS, isometric strength, and muscle thickness were compared among the three groups using a one-way analysis of variance (ANOVA). The distribution of unilateral/bilateral THA among the groups was determined using the chi-square test. Exercise compliance was compared between the two intervention groups using an unpaired t-test. For testing group differences between baseline and post-intervention data, we used an ANOVA to compare change scores between pre- and post-intervention data. If a significant group effect was detected, post hoc analysis with Holm adjustment was employed. All tests were conducted on a 5% significance level. An intention-to-treat analysis was performed using the last observation carried forward method. For statistical analysis, SPSS for Windows (version 20.0; SPSS

Inc., Chicago, IL, USA) was used.

Results

During the follow-up period, one participant in the WB group and three in the control group refused to undergo follow-up assessment for personal reasons. One participant in the NWB group discontinued the home exercise program because of visceral disease. Thus, follow-up data were available for 21 of 22 participants in the WB group, 20 of 21 in the NWB group, and 19 of 22 in the control group (Figure 1).

Table I shows that there were no significant differences among the groups in age, body weight, height, body mass index (BMI), implantation period, and unilateral/bilateral distribution (Table I). There were no significant differences among the groups in baseline functional performance, HHS, isometric strength, and muscle thickness (Table II, III, and IV). Exercise compliance as assessed by the logs showed no significant difference between the WB and NWB groups (86.9% vs. 83.9%, respectively; P = 0.62). There were no adverse effects from the WB or NWB exercise, such as dislocation of the prosthesis, falls during exercise, joint pain, and muscle soreness.

Functional Performance

One-way ANOVA indicated significant differences among the three groups in the pre-post changes for all functional performance measures (Table II). Compared with the control group, both exercise groups exhibited significant improvements in STS, TUG, SCT, and MWS; however, only the WB group showed significantly more improvement in 3MWT. Furthermore, the WB group showed significantly greater pre-post changes in STS ($P < 0.05$) and 3MWT ($P < 0.05$) compared with the NWB group.

HHS

One-way ANOVA showed a significant group difference in pre-post HHS ($P < 0.01$) (Table III). Although the pre-post change in HHS for the WB group was significantly greater than that for the control group ($P = 0.02$), there were no significant differences between the NWB and control groups ($P = 0.23$) or between the WB and NWB groups ($P = 0.15$).

Isometric Strength

Both the WB and NWB groups showed significantly more improvement by post hoc analysis than the control group in all isometric strength measures (Table III). However, there were no significant differences in the pre-post changes for any isometric strength measures between both intervention groups.

Muscle Thickness

The pre-post change in quadriceps muscle thickness was the only significant group difference by one-way ANOVA ($P = 0.03$) (Table IV). Although the pre-post change was significantly greater in the WB group than in the control group ($P = 0.01$), there were no significant differences between the NWB and control groups ($P = 0.75$) or between the WB and NWB groups ($P = 0.56$).

Discussion

We investigated the effects of WB and NWB exercises on functional performance, HHS, hip and knee isometric strength, and muscle thickness. The results partially supported our hypothesis that WB exercise would be more effective in improving functional performance and muscle strength. Among the functional performance tests, the WB group showed a significantly greater improvement in STS and 3MWT than the NWB group. On the other hand, compared with the control group, both the WB and NWB groups showed equally significant improvements in all isometric strength measurements. Exercise compliance in both groups was more than 83%, which is similar to or higher than in previous studies of home exercise intervention for THA participants.[25, 27] Furthermore, it appears that both the WB and NWB exercises were feasible for THA patients because only one participant dropped out in each intervention group, and there were no adverse events related to the exercise program.

Both intervention groups showed significant improvement in the functional performance measures STS, TUG, SCT, and MWS compared with the control group. This suggests that both the WB and NWB programs were effective for functional performance. A significant correlation between muscle strength and functional performance has been reported in people with hypokinesia.[38-40]

Therefore, we believe that increased muscle strength contributed to functional performance improvement. Among the functional performance tests, the pre-post changes in STS and 3MWT in the WB group were significantly higher than in the NWB group. The WB program included an STS exercise, which facilitated motor learning of the STS motion, in addition to increasing of muscle strength. With regard to the 3MWT, it is possible that the squat, STS, and opposite pelvic raises strengthened the hip adductor and ankle muscles in addition to the hip and knee muscles, which may have improved overall endurance of the lower extremity muscles. Furthermore, it is likely that the hip extension in gait posture and tandem gait exercises altered gait condition and improved gait efficiency.

There were no significant differences among the three groups in baseline HHS. The pre-post change in the WB group was significantly greater than in the control group; however, there was no significant difference between the NWB and control groups after the 8-week intervention. The NWB single-joint exercise prescribed for the NWB group was performed within the joint range of motion, but weight-bearing exercise performed by the WB group such as pelvic rotation, hip extension in the gait posture, and tandem gait exercises may have extended the internal and external rotation, extension, and adduction range of motion of the hip, therefore improving the range of motion score in HHS.

Both intervention groups showed significantly more improvement than the control group in all muscle strength tests, and there were no significant differences in pre-post changes between the WB and NWB groups. Thus, our study suggests that both WB and NWB exercises are effective at improving hip musculature and knee extensor muscle strength. The NWB straight-leg raises and hip abduction and extension exercises focused on hip musculature using only the lower-extremity weight, without external weights such as a sandbag or Thera-band. According to the overload principle, higher intensity exercise should be more effective at increasing muscle strength. However, the NWB exercises in this study seem to have provided adequate intensity for improving muscle strength in THA patients with weak muscles. Because the lower leg weighs less than the entire leg, we considered it to be too light a load for the NWB knee extensor and flexor exercises, and therefore, added the Thera-band as an external load. As a result, knee extensor strength showed great improvement in the NWB group. It is interesting that the WB and NWB exercises resulted in comparable muscle strength improvement. In the WB exercise program, the half squat, STS, and opposite-side pelvic raises appear to have particularly contributed to increased muscle strength because of high intensity on the lower extremity muscles.[41] Previous research reported that hip abduction exercise of the opposite hip in standing requires >60% of the maximal voluntary contraction of the gluteus medius,[42] and the opposite-side pelvic raises used in this study is similar to the opposite hip abduction exercise. With regard to increasing hip flexor strength, the iliopsoas muscle connecting the lumbar spine to the hip joint through the pelvis[43] may have acted to stabilize trunk movement during WB exercises in standing. Furthermore, because the anterior portion of the gluteus medius and rectus femoris muscles contribute to hip flexion movement,[44, 45] the improvement in hip abductor and knee extensor strength may have been linked to increasing hip flexor strength.

Only the quadriceps muscle thickness in the WB group showed significantly greater pre-post change compared with the control group. The other muscles, such as the gluteus in both intervention groups and the quadriceps in the NWB group, showed no hypertrophy. Because a previous study suggested that high-intensity training is effective for increasing quadriceps muscle thickness in individuals with THA,[22] we assumed that the quadriceps were more loaded in the WB than in the NWB exercises. The principle of training specificity might explain why only the WB group showed quadriceps hypertrophy, despite similar improvement in knee extensor strength in both intervention groups. Because the knee extension strength measurement was performed in the same manner as the NWB knee extension exercise, training specificity may have had an influence in the NWB group. Therefore, we speculate that overall knee extensor function improved more in the WB group than in the NWB group. Although atrophy and fatty degeneration in gluteus muscles after THA have been reported,[7, 46] it is not known if this myodegeneration can be altered by exercise. Despite the absence of significant hypertrophy of the gluteus maximus, medius, and minimus muscles, hip extensor and abductor strength improved significantly in both intervention groups. Therefore, these increases in muscle strength depend on neural drive adaptations such as recruitment and rate coding. Because muscle quality was not assessed by echo intensity,[47] we cannot confirm the possibility of recovery of fatty degeneration.

The participants in the present study had undergone THA at least 6 months prior. Therefore, spontaneous motor function improvement was unlikely, and any weakness could have become permanent. This study shows that prescribed exercise intervention can improve functional performance and muscle strength months or years after THA surgery and standard rehabilitation. We suggest that WB exercise is more beneficial for patients with THA than NWB exercise because it has a greater effect on STS ability and walking endurance than NWB exercise and it can also improve HHS. Although, in this study, the effectiveness of WB exercise was shown in patients more than 6 months after surgery, it should also be actively prescribed in the early postoperative period after THA surgery for suitable patients.

This study has several limitations. To equalize the WB and NWB exercise volumes, we designed the programs to be performed in about 30 min. However, the exercise loads were not precisely controlled, and it is possible that differences in the loads affected the results. It is an important limitation that the evaluators who conducted the tests were not blinded to group assignment. Because all participants were women and most of them were not obese (less than 30 of BMI), it is difficult to generalize the efficacy of WB and NWB exercise programs to men, to those who have undergone revision THA, and to obese subjects.

Conclusions

In summary, the present study demonstrates that the both WB and NWB exercises are effective interventions for functional performance and muscle strength. In particular, WB exercise significantly improves STS speed and gait endurance. Based on our results, we suggest that WB exercise should be prescribed to THA patients in the late postoperative phase.

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Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Table I. Subject characteristics for the 3 groups at baseline

	WB group	NWB group	Control group	P
N	22	21	22	
Age (y)	61.2 (5.3)	60.8 (8.4)	62.7 (6.7)	0.63
Height (cm)	152.7 (4.7)	155.9 (4.4)	154.7 (4.9)	0.09
Weight (kg)	51.9 (8.8)	53.1 (10.9)	52.5 (6.4)	0.91
BMI (kg/m^2)	22.3 (3.9)	21.8 (3.8)	21.9 (2.4)	0.87
Implantation period (month)	39.3 (16.0)	35.2 (22.8)	42.0 (28.9)	0.44
Unilateral/Bilateral	16/6	12/9	15/7	0.54

P: significance level (one-way analysis of variance).

Table II. Mean (SD) of functional performance at baseline and follow-up

		WB group		NWB group		Control group		P
STS (s)	Baseline	7.9	(1.0)	7.8	(1.6)	7.4	(1.6)	0.52
	Follow-up	6.6	(1.1)	7.0	(1.7)	7.3	(1.4)	
	Difference (95% CI)	-1.3	(-1.0 to -1.6)*†	-0.8	(-0.4 to -1.2)*	-0.1	(-0.5 to 0.2)	<0.01
TUG (s)	Baseline	6.6	(0.7)	6.4	(1.1)	6.4	(0.9)	0.72
	Follow-up	5.8	(0.8)	5.9	(1.4)	6.5	(0.9)	
	Difference (95% CI)	-0.8	(-0.5 to -1.0)*	-0.6	(-0.2 to -0.9)*	0.1	(-0.1 to 0.3)	<0.01
SCT (s)	Baseline	5.2	(0.9)	5.1	(0.9)	5.1	(1.1)	0.93
	Follow-up	4.6	(1.0)	4.7	(0.9)	5.1	(1.0)	
	Difference (95% CI)	-0.6	(-0.4 to -0.9)*	-0.4	(-0.1 to -0.6)*	0.0	(-0.2 to 0.2)	<0.01
MWS (m/s)	Baseline	1.82	(0.17)	1.88	(0.23)	1.91	(0.26)	0.38
	Follow-up	2.01	(0.25)	1.97	(0.29)	1.84	(0.24)	
	Difference (95% CI)	0.19	(0.10 to 0.28)*	0.09	(0.02 to 0.16)*	-0.07	(0.0 to -0.13)	<0.01
3MWT (m)	Baseline	264.2	(27.8)	267.1	(36.6)	266.5	(40.3)	0.96
	Follow-up	288.0	(33.7)	279.1	(39.0)	270.1	(35.0)	
	Difference (95% CI)	23.8	(17.9 to 29.7)*†	12.0	(6.7 to 17.4)	3.6	(-3.5 to 10.8)	<0.01

*Significant difference compared with the control group, P < 0.05; †Significant difference between the WB and NWB groups, P < 0.05; P: significance level (one-way analysis of variance); STS: sit-to-stand; TUG: timed up and go; SCT: stair climbing test; MWS: maximal walking speed; 3MWT: 3 min walk test; CI: confidence interval.

Table III. Mean (SD) of Harris hip score and isometric strength at baseline and follow-up

		WB group		NWB group		Control group		P
HHS	Baseline	88.1	(9.0)	91.5	(6.1)	90.2	(7.3)	0.33
	Follow-up	92.4	(6.0)	92.9	(6.4)	90.7	(7.2)	
	Difference (95% CI)	4.3	(1.6 to 6.9)*	1.4	(0.1 to 2.7)	0.5	(-0.3 to 1.3)	<0.01
Hip abductor (Nm/kg)	Baseline	1.00	(0.18)	0.97	(0.28)	1.04	(0.27)	0.68
	Follow-up	1.21	(0.25)	1.20	(0.32)	1.03	(0.26)	
	Difference (95% CI)	0.21	(0.12 to 0.31)*	0.22	(0.16 to 0.29)*	-0.01	(-0.06 to 0.05)	<0.01
Hip extensor (Nm/kg)	Baseline	1.10	(0.27)	1.09	(0.21)	1.10	(0.23)	0.99
	Follow-up	1.29	(0.27)	1.33	(0.28)	1.08	(0.24)	
	Difference (95% CI)	0.19	(0.10 to 0.28)*	0.23	(0.16 to 0.31)*	-0.02	(-0.07 to 0.03)	<0.01
Hip Flexor (Nm/kg)	Baseline	0.92	(0.25)	1.06	(0.29)	0.94	(0.17)	0.16
	Follow-up	1.14	(0.22)	1.20	(0.27)	0.96	(0.17)	
	Difference (95% CI)	0.21	(0.14 to 0.28)*	0.15	(0.08 to 0.21)*	0.02	(-0.02 to 0.06)	<0.01
Knee extensor (Nm/kg)	Baseline	1.81	(0.54)	1.56	(0.29)	1.71	(0.43)	0.19
	Follow-up	2.10	(0.62)	1.78	(0.36)	1.75	(0.46)	
	Difference (95% CI)	0.29	(0.19 to 0.39)*	0.22	(0.12 to 0.32)*	0.04	(-0.03 to 0.11)	<0.01

*Significant difference compared with the control group, P < 0.05; P: significance level (one-way analysis of variance); HHS: Harris hip score; CI: confidence interval.

Table IV. Mean (SD) of muscle thickness at baseline and follow-up

		WB group		NWB group		Control group		P
Gluteus maximus (mm)	Baseline	22.9	(7.0)	19.8	(4.5)	21.5	(4.1)	0.20
	Follow-up	24.3	(5.0)	21.7	(4.4)	21.7	(4.1)	
	Difference (95% CI)	1.5	(-0.7 to 3.7)	0.8	(-0.4 to 4.3)	0.2	(-1.3 to 1.8)	0.76
Gluteus medius (mm)	Baseline	31.6	(6.8)	35.6	(6.2)	32.0	(4.1)	0.06
	Follow-up	32.9	(6.0)	36.6	(6.3)	32.4	(4.8)	
	Difference (95% CI)	1.4	(-0.4 to 3.1)	1.0	(-0.2 to 2.2)	0.4	(-1.2 to 2.0)	0.65
Gluteus minimus (mm)	Baseline	11.8	(3.5)	11.0	(1.4)	11.4	(3.3)	0.66
	Follow-up	12.7	(2.9)	11.6	(1.3)	10.6	(2.4)	
	Difference (95% CI)	0.9	(-0.3 to 2.0)	0.6	(-0.2 to 1.4)	-0.8	(-2.1 to 0.5)	0.06
Quadriceps femoris (mm)	Baseline	24.1	(5.8)	25.0	(4.4)	24.7	(4.0)	0.81
	Follow-up	26.2	(5.6)	26.0	(4.1)	24.8	(4.4)	
	Difference (95% CI)	2.1	(1.0 to 3.3)*	1.0	(-0.3 to 2.3)	0.1	(-0.7 to 1.0)	0.03

*Significant difference compared with the control group, $P < 0.05$; P: significance level (one-way analysis of variance); CI: confidence interval.

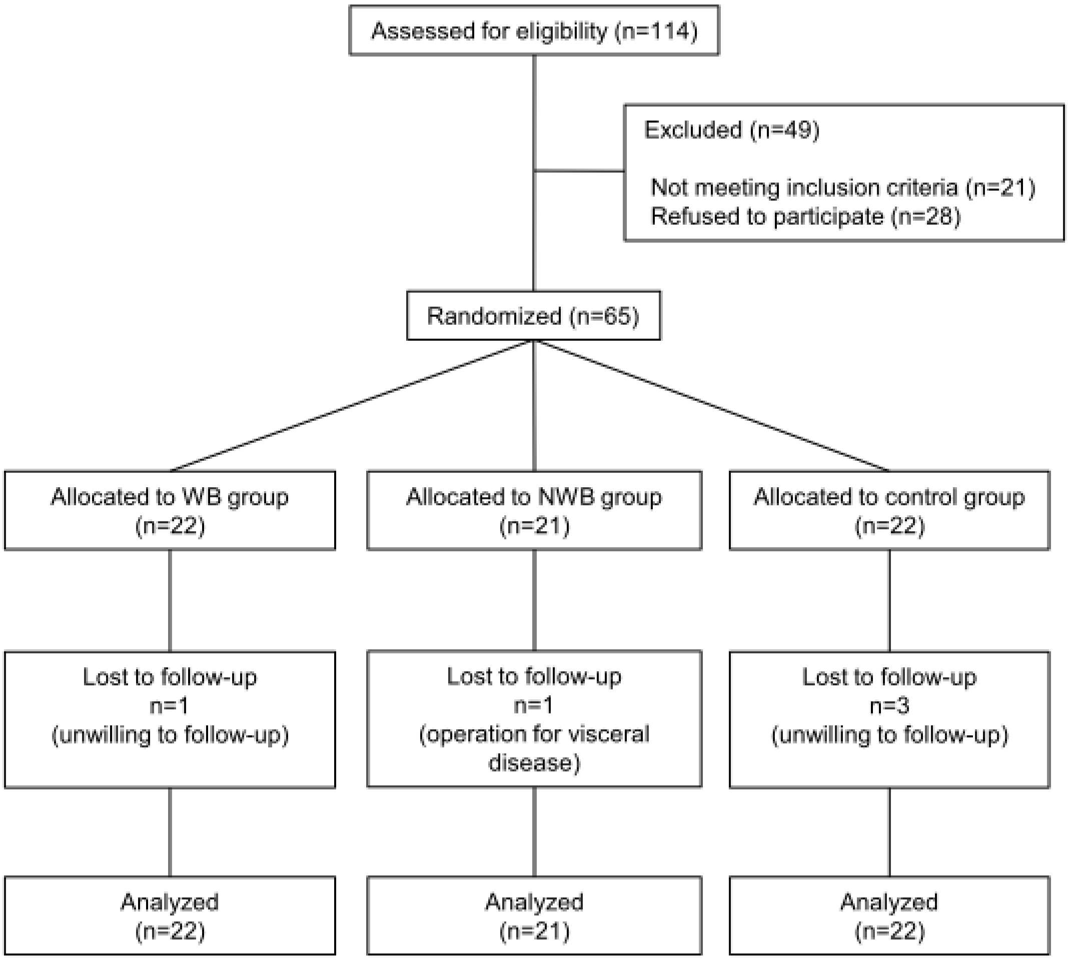

Figure 1. Flowchart of participant enrollment, intervention, and analysis.

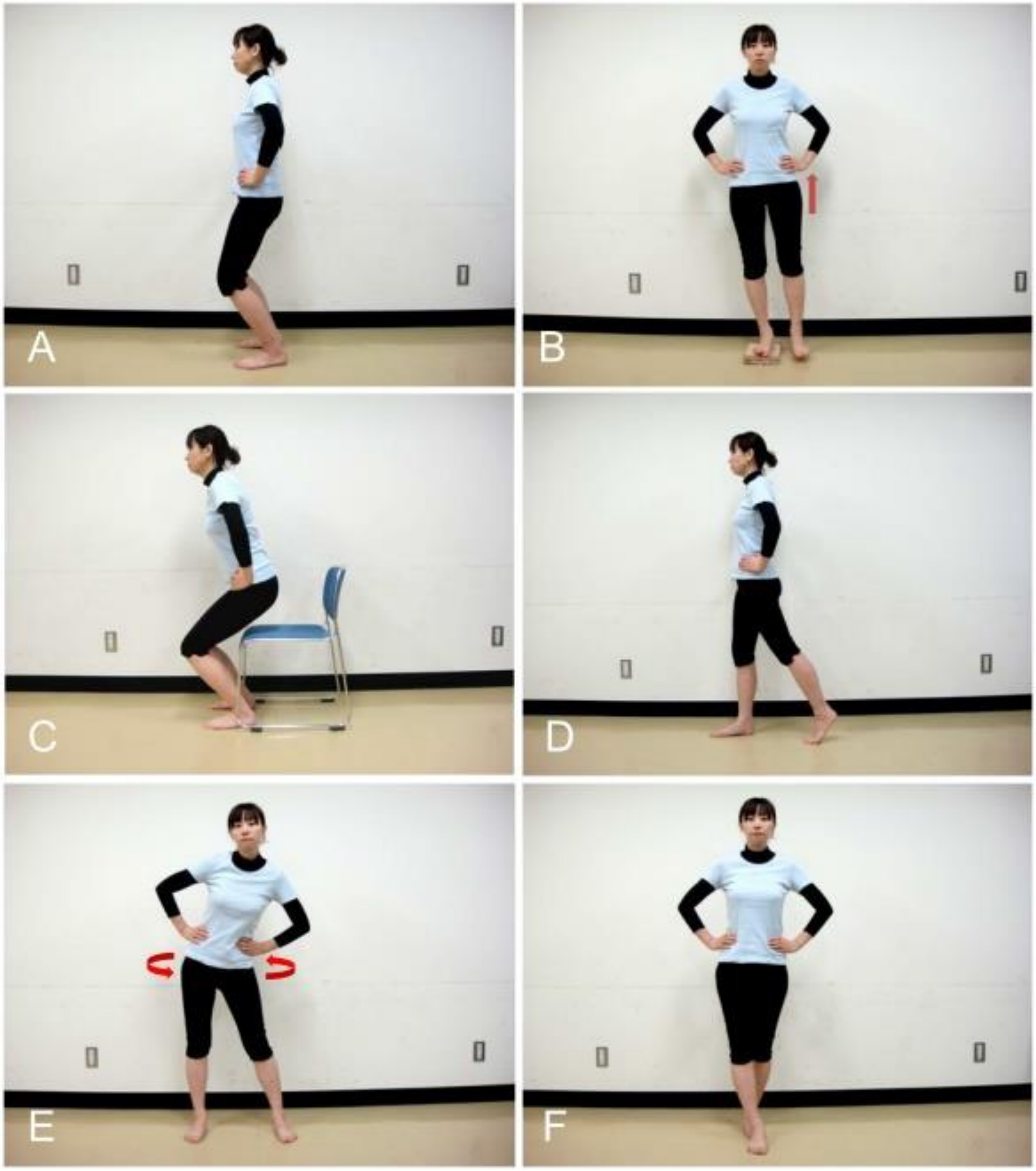

Figure 2. Exercise program for the group.

A) Half squats; B) opposite-side pelvic raises; C) sit-to-stand from a chair; D) hip extension in gait posture; E) pelvic rotations; F) tandem gait.

Figure 3. Exercise program for the non-weight-bearing group.

A) Straight leg raises; B) bridging; C) hip abduction; D) hip extension; E) knee extension; F) knee flexion.

参考論文

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Factors associated with restricted hip extension during gait in women after total hip arthroplasty

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ABSTRACT

Purpose: A decreased peak hip extension angle in the late stance phase is a major gait abnormality in patients with THA. The purpose of this study was to determine the relationship between peak hip extension angle during gait and functional impairments such as muscle weakness and the limitation in joint range of motion and to identify the clinical factors influencing peak hip extension angle during gait.

Methods: 67 female volunteers with THA were examined. Biomechanical gait analysis was performed to measure peak hip extension angle during gait. Maximal isometric strength of the hip and knee, passive hip extension range of motion, leg length discrepancy, and hip pain were assessed.

Results: Peak hip extension angle during gait significantly correlated with passive hip extension range of motion ($r = 0.259$), hip pain ($r = -0.264$), isometric strengths of the hip musculature ($r = 0.278$-0.491), and knee extensor ($r = 0.386$). Stepwise multiple regression analysis revealed that hip abductor torque ($\beta = 0.355$, $P = 0.001$), hip pain ($\beta = -0.353$, $P = 0.001$), and passive hip extension range of motion ($\beta = 0.258$, $P = 0.011$) were significant contributors to peak hip extension angle during gait ($R^2 = 0.408$).

Conclusions: Our findings suggest that THA rehabilitation aimed at improving gait ability should focus on strengthening the hip abductors, controlling hip pain and increasing range of motion of hip extension.

Keywords: Total hip arthroplasty, Gait, Rehabilitation

Introduction

Despite the success of total hip arthroplasty (THA) patients do not always acquire normal gait ability. Abnormal gait is influenced by factors such as increased trunk lateral bending in mid-stance, increased anterior pelvic/rotation and decreased sagittal plane hip motion. These factors may remain for several years after THA (1-6). A decreased peak hip extension angle (PHEA) in the late stance phase, in particular, has been highlighted in many previous studies as a significant factor affecting gait (1-4, 6). Because inadequate hip extension decreases hip flexor power absorption and inhibits energy storage in the hip flexor muscle (which has the functional role of pulling the leg forward to assist swing initiation (4)) it may lead to decreased swing speed and shortened stride length, accompanied by slowing of gait velocity.

For effective recover y from gait disturbance, it is essential to focus on the factors influencing abnormal gait during postoperative rehabilitation. Functional impairments, such as lower extremity muscle weakness (7-9) and restriction of hip range of motion (ROM) (10), persist for an extended period after THA, and it is possible that these impairments are associated with abnormal gait. Few studies have investigated these relationships, thus, it is unclear as to which specific impairments affect gait abnormality after THA.

The purpose of this study was to investigate the relationship between functional impairments and PHEA during gait, which is a typical gait abnormality in THA patients, and to identify the factors influencing PHEA during gait. We hypothesised that PHEA is influenced by hip flexor and hip abductor muscles, which, in addition to the passive hip extension angle, generate strong force in the late stance phase.

Methods

Participants

Adult women with THA who lived in the community were recruited from two hospitals in Kyoto, Japan. Participants were included if they were diagnosed with osteoarthritis as the primary reason for THA, had undergone primary THA more than 6 months prior to the study, had completed 4-6 weeks supervised postoperative rehabilitation program, and had the ability to walk more than 50 m independently without the use of a walking aid. Exclusion criteria were: hip revision surgery; infection of the prosthesis; central or peripheral nervous system involvement; another musculoskeletal disorder affecting walking; or cognitive problems. The participants' general characteristics, including age, height, weight, months since THA, side of THA, and Harris Hip Score (HHS, range from 0 to 100, and 100 indicate best functioning), are shown in Table I.

This cross-sectional study was approved by the Ethical Board of Kyoto University, Graduate School of Medicine. Informed consent was obtained from all participants prior to the study.

Measurement of PHEA during gait

PHEA was measured using a six-camera Vicon motion system (Vicon Nexus; Vicon Motion

Systems Ltd. Oxford, England) at a sampling rate of 200 Hz. The participants were clothed in tight-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). 16 markers were bilaterally placed on the anterior superior iliac spine, posterior superior iliac spine, lateral thigh, lateral femoral epicondyle, lateral shank, lateral malleolus, second metatarsal head, and calcaneus. Each camera was calibrated before data collection.

Participants were requested to walk barefoot on an 8 m walkway at their self-selected speed and were tested after several familiarisation trials. At least 3 successful trials for each participant were recorded for analysis. Marker trajectories were filtered using a Woltring filter, with a mean-squared error value of 10. Vicon nexus version 1.7.1 software was used to calculate the relative angles between coordinate systems of each segment in the lower limb (11). PHEA was identified and an average value of three trials was used for analysis.

Measurement of hip extension ROM

Hip extension ROM was recorded by 2 experienced physical therapists using a standard goniometer with a 1°-scale. One examiner treated the lower extremity, and the other examiner performed the measurement. Hip extension ROM was measured in the supine position with the contralateral hip passively flexed and the bilateral anterior superior iliac spines manually held to stabilise pelvic movement (Fig. 1). The measurement was performed once. The high reliability of goniometric measurements of hip ROM in patients with osteoarthritis has been demonstrated in previous research (12).

Measurement of leg length discrepancy (LLD)

LLD was calculated as the difference in the length of each lower extremity after measuring the distance between the anterior superior iliac spine and the medial malleolus with a tape measure. The participants were in the supine with neural hip rotation, and the hip and knee were extended to 0°. Previous research demonstrated the excellent validity when compared to CT scans and excellent test-retest reliability of tape measure method (13).

Pain evaluation

The participants recorded their hip pain during walking on a 100-mm visual analogue scale, in which 0 mm represented no pain at all and 100 mm represented “the worst pain I can imagine.” Good test-retest reliability of the pain evaluation using visual analog scale was demonstrated in the previous study (14).

Measurement of maximum isometric strength

Peak torque during maximum isometric contraction of the hip abductor, extensor and flexor were measured using a hand-held dynamometer (HHD; MEDIX, Tokyo, Japan), and the peak torques of the knee extensor and flexor were measured using a stationary dynamometer (ISOFORCE GT-330, OG Giken, Tokyo, Japan). Good test–retest reliabilities for these measurements have been verified in previous studies on THA patients (15, 16). Strength tests were performed in the following order for each participant: hip abductor, extensor, and flexor and knee extensor and flexor. The position of the patient for each muscle test was as follows: hip abductor, supine with neutral hip adduction/abduction; hi p extensor, prone with neutral hip flexion/extension; hip flexor, seated on a platform with 90° hip and knee flexion, and leg perpendicular to the floor with foot off the floor; knee extensor and flexor, seated on a stationary dynamometer with the hip flexed to 90° and the knee flexed to 60°. The sensor pads of HHD were placed on the lateral, posterior, and anterior thigh just proximal to the knee joint for the hip abductors, extensors, and flexors. The distal edge of the shin attachment of the stationary dynamometer was placed 5 cm proximal to the lateral malleolus of the test leg for the knee extensor and flexor. The lengths (m) of the lever arms were measured from the estimated center of rotation of the hip and knee joint to the center of the sensor pad of HHD and shin attachment of stationary dynamometer. After three practice trials, the higher value of two trials was obtained. Each strength value (N) and lever arm (m) were converted into a ratio of torque to body weight (Nm/kg).

Statistical analysis

Descriptive statistics were used to summarise the demographic data and all outcome measurements. Data were analysed using the Shapiro–Wilk test for normal distribution. The relationships between PHEA and the other variables of interest were evaluated using Pearson correlation coefficients and Spearman rank–correlation coefficients for parametric and non-parametric data, as appropriate. A stepwise multiple regression analysis was performed with PHEA as the dependent variable. The independent variables were age, body mass index (BMI), time since THA, hip extension ROM, LLD, hip pain, and maximal isometric strength of the affected hip and knee. All statistical analyses were conducted using SPSS 20.0 software (SPSS Inc., Chicago, USA). The level of statistical significance was set at $P<0.05$.

Results

Of the 116 women who underwent THA and were screened by review of medical records and recruited, 21 did not meet the inclusion criteria and 28 declined to participate. The remaining 67 women participated in this research and completed all the experimental procedures. Table I summarises the participants' demographic characteristics. The average age ± SD was 61.9 ± 6.7 years, the mean time since THA was 50.3 ± 40.0 months, and the mean HHS was 90.0 ± 7.4 point. Of the 67 participants, 22 had bilateral THA. For participants who underwent bilateral THA, the side exhibiting the more pronounced limp was determined by observational gait analysis performed by 3 physical therapists with 12, 9, and 9 years experience. All 3 physical therapists agreed on the side to be assessed for all subjects with bilateral THA. THA surgery in all subjects was performed using the anterolateral approach, and there were no restrictions on weight-bearing after surgery.

Table II showed the results of all measurements. The mean values were 6.9 ± 6.8° for PHEA, 11.1 ± 4.5° for hip extension ROM, 2.1 ± 10.7 mm for LLD, and 2.0 ± 5.9 mm for hip pain. Maximal isometric strengths were 1.00 ± 0.22 Nm/kg for the hip abductor, 1.08 ± 0.22 Nm/kg for the hip extensor, 0.98 ± 0.21 Nm/kg for the hip flexor, 1.76 ± 0.49 Nm/kg for the knee extensor, and 0.76 ± 0.17 Nm/kg for the knee flexor.

No significant correlations were found between PHEA and age, BMI, or time since THA (Tab. III). Hip extension ROM and pain were significantly correlated with PHEA (hip extension ROM, r = 0.259, P = 0.035; pain, r = -0.264, P = 0.031). All isometric strengths except for knee flexor strength showed significant correlations wit h PHEA (hip abductor torque, r = 0.491, P = 0.000; hip extensor torque, r = 0.372, P = 0.002; hip flexor torque, r = 0.278, P = 0.023; knee extensor torque, r = 0.386, P = 0.001).

A stepwise multiple regression analysis revealed that hip abductor torque, hip pain, and hip extension ROM were the significant contributors to PHEA during gait (Tab. IV). The regression model with only the hip abductor strength had an adjusted R^2 = 0.241, whereas the model consisting of all 3 selected contributors had an adjusted R^2 = 0.408 (hip abductor torque, β = 0.355, P = 0.001; pain, β = -0.353, P = 0.001; hip extension ROM, β = 0.258, P = 0.011).

Discussion

This study revealed that restricted hip extension in late stance phase in women following THA was associated with pain, passive hip extension ROM, and hip and knee muscle strength. In addition, hip abductor strength, hip pain, and passive hip extension ROM independently influenced the restriction of hip extension. These results partially supported our hypothesis that hip abductor and flexor muscle strengths and passive ROM would be predictors of restricted hip extension. Although participants of this study had a normal level of motor function as people following THA (average of HHS, 90.0), PHEA during gait was obviously restricted (mean angle, 6.9°). Abnormal gait lasted for more than 6 months after THA.

PHEA during gait is generally decreased in the elderly compared with younger people (17, 18); however, there was no significant correlation between PHEA and age in the present study, probably because of the small participant age of 49-76 years. In addition, a previous study showed that there were no significant differences in the hip extension angle during gait in THA patients over 50 years (3). Therefore, it is unlikely that people with THA who already have restricted hip extension during gait due to hip osteoarthritis or THA surgery would have further hip extension restriction due to aging. There was also no significant correlation between PHEA during gait and the time since THA in this study. In a gait analysis study focusing on the longitudinal preoperative and postoperative change with THA, hip sagittal motion increased for 6 months after surgery; however, there was no significant kinematic difference between 6 and 12 months (6). Since patients continue to have restricted hip extension motion during gait 10 years after THA (3), abnormal gait following THA may not improve after a certain period. LLD was also not associated with PHEA during gait. This result agrees with a previous study indicating that LLD does not influence the hip extension angle during gait in patients after THA (19).

Hip abductor torque, hip pain, and passive hip extension ROM were selected as significant contributors to PHEA during gait by stepwise regression analysis, with the hip abductor torque being the largest contributor to the same. Because the hip abductor plays an important role in the stability of the pelvis in single stance phase during gait (20), high hip abductor strength may stabilise the pelvis for smooth hip joint extension in the late stance phase. Though the hip extension motion in the late stance phase is controlled by eccentric contraction of the iliopsoas muscle, the anterior portion of the gluteus medius muscle also has hip flexor function (21) and displays relatively high muscular tension in late stance phase (22); therefore, it may directly control hip extension movement, in addition to stabilising the pelvis. Furthermore, since hip abductor strength is very important for preventing a decrease in the hip abduction moment in stance phase (23), progressive hip abductor strength training is strongly recommended for rehabilitation after THA. In contrast, despite having a significant correlation to PHEA during gait, both the hip extensor and flexor strengths were not selected as significant contributors by regression analysis. Because the hip extensor acts primarily in the loading response at the initiation of the stance phase, and muscle tension evoked in the late stance phase is very low and it did not directly influence hip extension motion. The hip flexor controls hip extension motion by evoking muscle tension by eccentric contraction. However, in the present study, muscle strength was evaluated in isometric contraction, rather than assessing eccentric ability. This difference may explain why the hip flexor was not selected as a significant contributor.

Regression analysis revealed that hip pain was one of the significant contributors to PHEA. Hip pain is known to continue in 0.4-18% patients after THA (24). Iliopsoas impingement, aseptic loosening of the acetabular component, bursitis, adverse reactions to metal debris, infection, so-called “thigh pain” and others are known to cause hip pain after THA (24). The primary cause of hip pain was not investigated in the present study. To obtain more ideal gait pattern in patients with hip pain after THA, the cause of pain should be determined, and the appropriate medical treatment should be provided.

Reduction of passive hip extension ROM was the significant contributor to PHEA during gait, and this fact suggests that hip extension motion is restricted in relation to passive hip extension ROM after THA. The passive hip extension ROM of the participants in this study was clearly less than that in healthy people (25), with an average value was 11.0°. Restriction in passive hip extension ROM in hip osteoarthritis patients is one of the major impairments due to deformity of the joint and reduction in expansibility of soft tissue, such as muscle and the joint capsule (26), and it may continue even after THA. Thus, it is important to perform careful hip extension ROM exercise before and after THA, with particular attention to dislocation of the prosthesis.

The determination coefficie nt of the regression model consisting of the three extracted variables was 0.435, which can explain only 44% of PHEA during gait. The remaining 56% must be due to factors not included in this model. For example, hip rotation muscle strength was not treated as an explanatory variable. However, because the hip external rotator is considered to contribute to stability of the hip joint, it may influence the hip joint motion during gait. It has been reported that decreased hip muscle power is compensated for by greater ankle power during walking in patients with THA (1, 27). Tateuchi et al (28) showed that walking exercise with decreased ankle push-off can extend the hip extension angle and increase hip flexor power. According to these reports, for THA rehabilitation, it is important not only to improve hip abductor strength and hip ROM but also gait pattern motor learning. Furthermore, because postoperative gait is influenced by preoperative gait (29), as much as possible, preoperative rehabilitation should include walking exercise to prevent the development of an abnormal gait pattern.

Some limitations of this study should be taken into account. Obesity is a major problem in THA patients. Because there was only one participant in this study with a BMI above 30, it is possible that the results underestimated the consequences of obesity on PHEA during gait. This study also included both unilateral and bilateral THA patients and did not take into account the influence of the operative side. The operative procedure, such as the incision approach or the use of a mini-incision, was not also considered. However, because previous research has shown little difference on gait performance between a mini-incision and a conventional approach (30-33), the effect of the surgical approach on gait might be vanishingly small.

Hip abductor strength, hip pain and hip extension ROM are independently associated with abnormal gait posture following THA in women, accounting for 44% of the variance in PHEA during gait. The findings of this study support the recommendation for incorporation of hip abductor strength training, hip extension ROM exercise, and pain treatment in order to improve gait ability.

Disclosures

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Conflict of interest: None.

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Table I: Descriptive characteristics of the participants

Characteristics	Mean or no.	SD or %
Age	61.9	6.7
Weight (kg)	52.5	8.5
Height (cm)	154.5	4.7
BMI (kg/m^2)	22.0	3.3
THA operation		
Unilateral	45	67.2
Bilateral	22	32.8
Time since THA (month)	50.3	40.0
HHS (0-100)	90.0	7.4

Table II: Mean and SD values for each measured variable

Variables	Mean	SD
PHEA (degree)	6.9	6.8
Hip extension ROM (degree)	11.1	4.5
LLD (mm)	2.1	10.7
Pain (mm)	2.0	5.9
Hip abductor torque (Nm/kg)	1.00	0.22
Hip extensor torque (Nm/kg)	1.08	0.22
Hip flexor torque (Nm/kg)	0.98	0.21
Knee extensor torque (Nm/kg)	1.76	0.49
Knee flexor torque (Nm/kg)	0.76	0.17

Table III: Pearson correlation coefficients between PHEA and each variable of interest

Variables	Correlation coefficients	*P*
Age	0.206	0.095
BMI	0.051	0.681
Time since THA	0.164	0.185
Hip extension ROM	0.259*	0.035
LLD	−0.083	0.504
Pain	−0.264*	0.031
Hip abductor torque	0.491*	0.000
Hip extensor torque	0.372*	0.002
Hip flexor torque	0.278*	0.023
Knee extensor torque	0.386*	0.001
Knee flexor torque	0.086	0.487

*Statistically significant at $P < 0.05$.

Table IV: Stepwise multiple regression using PHEA as the dependent variable

Independent Variables	R^2 (R^2_{adj})	R^2 Change	B (SE) (unstandardized coefficient)	β (standardized coefficient)	*P*
Model 1	0.241 (0.230)	0.241			
Hip abductor torque			15.133 (3.328)	0.491	0.000
Model 2	0.374 (0.355)	0.133			
Hip abductor torque			13.081 (3.096)	0.425	0.000
Pain			−0.427 (0.116)	−0.371	0.000
Model 3	0.435 (0.408)	0.061			
Hip abductor torque			10.936 (3.077)	0.355	0.001
Pain			−0.407 (0.111)	−0.353	0.001
Hip extension ROM			0.392 (0.150)	0.258	0.011

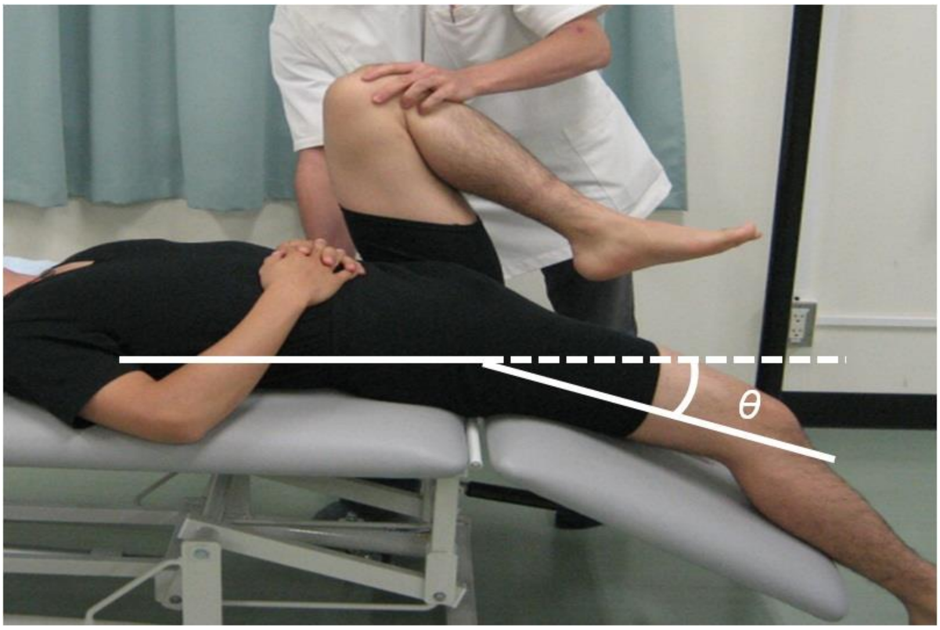

Figure 1. ROM measurements of hip extension