J Orthop Sci (2007) 12:550–554
DOI 10.1007/s00776-007-1178-2

JOURNAL OF
ORTHOPAEDIC SCIENCE

Original article

Gait analysis of patients in early stages after total hip arthroplasty: effect of lateral trunk displacement on walking efficiency

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Abstract

Background. Control of the mediolateral displacement of the center of gravity (COG) is considered to be important for efficient walking. Few studies have been published on the relation between walking efficiency and the lateral displacement of the trunk, pelvis, or COG in patients soon after total hip arthroplasty (THA). The present study was undertaken to examine the effects of lateral displacement on walking efficiency after THA.

Methods. The subjects of this study were 15 women who had undergone unilateral THA 4 weeks before and 14 healthy women as controls. Using a force plate and a three-dimensional motion analyzer, we measured (1) gait speed, stride length, cadence; (2) lateral trunk displacement (LTD) and lateral pelvis displacement (LPD); (3) lateral displacement of the center of gravity; and (4) the total internal work done per unit mass and distance walked (a negative index of walking efficiency) (WE^{-1}).

Results. Compared with healthy persons, THA patients showed significantly increased amplitude of LTD and greater WE^{-1} ($P < 0.01$). The WE^{-1} value of the THA group was 21.4% higher than that of the control group. The results suggest that the patients need more energy to progress their body forward in a gait cycle, indicating reduced walking efficiency. In THA patients, the stepwise multiple regression analysis selected LTD as the sole significant variable affecting WE^{-1} ($R^2 = 0.72$, $P < 0.01$).

Conclusions. These results suggest that trunk compensation strategy for hip abductor weakness in patients soon after THA can lead to increased energy expenditure.

Introduction

Total hip arthroplasty (THA) is a common surgical procedure performed in patients with osteoarthritis of the hip. THA is effective in relieving pain and improving the function and mobility of the hip. However, some studies have shown that THA patients have difficulty regaining a normal pattern of walking for several years after surgery.[1–4]

The common gait disturbances seen in patients with osteoarthritis and after THA include excessive lateral bending of the trunk toward the affected side. The trunk inclination toward the affected limb could be used to compensate for weakened hip abductor muscles and to keep the balance of the body in the frontal plane.[2–4] Madsen et al.[4] have noted that this trunk movement is also used as a pain avoidance mechanism that reduces the contact forces at the hip joint. However, the trunk compensation strategy can lead to pathological changes in the knee and ankle joints over a period of years.[5] In particular, Perry[6] noted that valgus deformity of the knee can be caused by laterally displaced weight over the hip joint.

To progress forward efficiently and control balance during walking, the pelvis and upper body move rhythmically from side to side in time with alternate steps.[7] Hip abductor muscle strength is essential for the optimization of this lateral displacement.

In general, control of the mediolateral displacement of the center of gravity (COG) is considered important for efficient walking.[7,8] An excessive excursion of COG in the frontal plane in THA patients may result in a lack of walking efficiency. Therefore, recovery of hip abductor muscle strength and normalization of the mediolateral movement during walking is an important goal of physical therapy for THA patients.

Until now, few studies have been published on the relation between walking efficiency and lateral displacement of the trunk, pelvis, or COG after THA. Understanding walking patterns soon after THA, when the muscle strength has not fully recovered, is critical for planning postoperative rehabilitation interventions.

The purpose of this study was to identify the factors affecting lateral displacement in patients soon after

Offprint requests to: M. Nankaku
Received: February 23, 2007 / Accepted: August 27, 2007

THA surgery and to assess their effect on the efficiency of walking.

Materials and methods

Subjects

Participants of this study comprised 15 female patients who had undergone THA surgery at the Department of Orthopedic Surgery, Kyoto University Hospital, between June 2004 and April 2005 (THA group). Our inclusion criteria were (1) primary THA for unilateral hip osteoarthritis; (2) no symptoms involving the contralateral hip, knee, or ankle; and (3) informed consent for participation in the study. Fourteen age-matched healthy women were recruited from the local community and the staffs of Kyoto University Hospital as a control group. The two groups did not differ significantly in age, height, weight, or body mass index (Table 1).

All patients had undergone primary THA using an anterolateral (Dall's) approach, 10 patients with cemented prostheses and 5 with noncemented prostheses. Full weight bearing was started on the third postoperative day, and all patients received their prescribed 4-week rehabilitation program while staying in hospital. All patients were able to walk independently without any assistive device, and none had severe pain during walking at 4 weeks after surgery, when the analyses were performed. In all patients, hip abductor muscle strength of the affected side was at a poor level (2/5), and that of the unaffected side was at a normal level (5/5), according to Daniels's manual muscle testing. The limb-length discrepancy, as measured by the side difference in the distance between teardrop and tip of the lesser trochanter on anteroposterior (AP) radiographs, was within 1 cm. Prior to the study, each subject was informed in detail of the design and objectives of the study and agreed to be involved in the study.

Analysis system and procedure

Gait analysis was performed using a three-dimensional motion analyzer (GAITAL-ITS-60; Sumitomo Metal Industries, Osaka, Japan) composed of four charge-coupled device cameras and two floor reaction force platforms (9090S; Bertec, Columbus, OH, USA). The sampling frequency was 240 Hz for the floor reaction platform data and 60 Hz for the three-dimensional data. Reflective markers were attached to 11 points on the body surface (manubrium of the sternum, acromions, anterosuperior iliac spines, greater trochanters, lateral supracondylar points, centers of lateral malleoli) of each subject. Participants walked on an 8-m walkway without any assistive device while wearing their own shoes and at a self-selected speed. Prior to testing, all participants practiced walking several times.

Table 1. Subject characteristics

	THA ($n = 15$)		Control ($n = 14$)		
Characteristic	Mean	SD	Mean	SD	*P*
Age (years)	47.0	10.2	46.0	13.2	NS
Weight (kg)	48.3	5.8	50.2	4.9	NS
Height (cm)	154.2	3.3	155.8	4.2	NS
BMI (kg/m^2)	20.3	2.2	20.7	1.9	NS

THA, total hip arthroplasty; BMI, body mass index

Data analysis

Kinematics analysis

Gait speed was calculated using the manubrium of the sternum as a position marker and determining its average speed in the forward direction for one gait cycle. Then, stride length was calculated by multiplying the gait speed by the time needed for one gait cycle. The cadence was calculated by dividing gait speed by stride length.

On the basis of three-dimensional measurements, the maximum deviations of the midpoints between the acromions and between anterosuperior iliac spines in the frontal plane from one side to the other (peak-to-peak changes over one gait cycle) were obtained as indices of lateral trunk displacement (LTD) and lateral pelvis displacement (LPD), respectively.

Kinetic analysis

Fx, Fy, and Fz were defined as lateral, fore-aft, and vertical force, respectively, representing the floor reaction force projected on three coordinate axes. The velocity of COG was obtained from the integration of acceleration (reaction force divided by body mass — Fx/M) in each direction over one gait cycle. The displacement of COG was provided by the integration of velocity.

Then, the displacement diagram in the frontal plane of COG was drawn. The lateral excursion of COG (LCOG) was also obtained from the width of displacement (the peak-to-peak change over one gait cycle).

The total energy of COG is the sum of the potential energy and the kinetic energy calculated as:

$$TE = M \cdot g \cdot (Dz - Dz_{min}) + M \cdot [Vx^2 + (Vy + Vy_{mean})^2 + Vz^2]/2$$

where M is the body mass, g is the acceleration due to gravity, Dz_{min} is the lowest value of vertical displacement of COG, and Vy_{mean} is the mean velocity in one cycle.

The total internal work done during one gait cycle was then calculated as

$$Wt = \int|\Delta TE|dt$$

as defined by Winter et al.[9] The total internal work done per unit mass and distance walked was calculated as a negative index of walking efficiency (WE^{-1}).[10]

Statistical analysis

The mean of three trials achieving good contact with the two floor reaction platforms and adequate follow-up of markers was adopted for data analysis. The unpaired Student's *t*-test was used to examine differences between the THA and control groups. The levels of association between WE^{-1} and the gait speed, LTD, LPD, and LCOG were first examined with Pearson's correlation coefficients. Then, stepwise multiple regression analysis was performed with WE^{-1} as a dependent variable and the gait speed, LTD, LPD, and LCOG as independent variables. Statistical analysis was performed using Stat View 5.0 software, with $P < 0.05$ regarded as statistically significant.

Results

The THA patients had a significantly lower mean gait speed, stride length, and cadence than did healthy people (the control group) (Table 2). The mean amplitudes of LTD were 7.90 ± 2.81 cm and 5.01 ± 1.54 cm in the THA and control groups, respectively. The difference in LTD between the groups was statistically significant ($P < 0.01$) (Fig. 1). The mean amplitudes of LPD during one gait cycle were 5.62 ± 1.54 cm and 4.98 ± 1.46 cm in the THA and control groups, respectively. The difference in LPD was not significant (Fig. 1).

There was no difference between the two groups regarding the amplitude of LCOG during one gait cycle (Table 2). Figure 2 shows the pattern of COG movement in the frontal plane. The control group showed a U-shaped pattern of COG movement in the frontal plane. On the other hand, the THA group demonstrated an asymmetrical pattern of COG movement with higher COG during the stance phase of the affected limb.

The value for WE^{-1} was significantly greater in the THA group than in the control group ($P < 0.01$) (Table 2), indicating inefficient COG displacement in the THA group.

Table 3 shows Pearson's coefficient of correlation between WE^{-1} and the gait speed, LTD, LPD, and LCOG in both groups. In the THA group, WE^{-1} was positively correlated with LTD (Fig. 3) and LCOG. WE^{-1} was not correlated with the gait speed or LPD. In the control group, WE^{-1} was also correlated with LCOG. The stepwise multiple regression analysis identified LTD as the only factor determining WE^{-1}. LTD accounted for 72.1% of the variability of walking efficiency during the early postoperative period after THA.

Table 2. Gait parameters in THA patients and healthy women

Parameter	THA (n = 15) Mean	SD	Control (n = 14) Mean	SD	P
Gait speed (m/min)	49.9	8.8	69.0	6.2	<0.01
Stride length (m)	0.99	0.14	1.20	0.10	<0.01
Cadence (step/min)	102.9	8.8	115.4	11.1	<0.01
Displacement of COG (cm)	3.71	1.17	3.15	0.73	NS
WE^{-1} (J/kg/m)	0.87	0.18	0.69	0.12	<0.01

COG, center of gravity; WE^{-1}, total internal work done per unit mass and distance walked

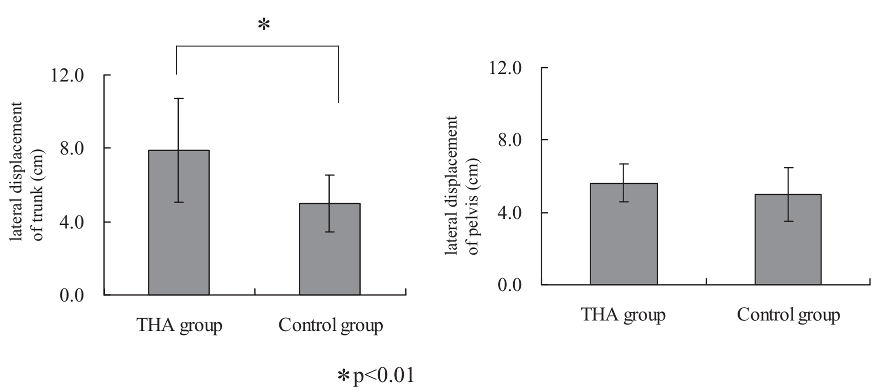

Fig. 1. Amplitude of lateral displacement of the trunk and pelvis in 15 total hip arthroplasty (THA) patients and 14 healthy women

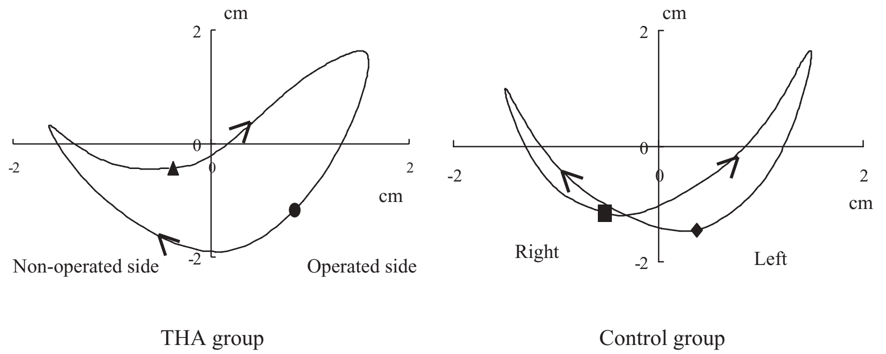

Fig. 2. Displacement diagrams of COG in the frontal plane in 15 THA patients and 14 healthy women. *Filled triangle*, heel contact of the operated side; *filled circle*, heel contact of the nonoperated side; *filled square*, right heel contact; *filled diamond*, left heel contact

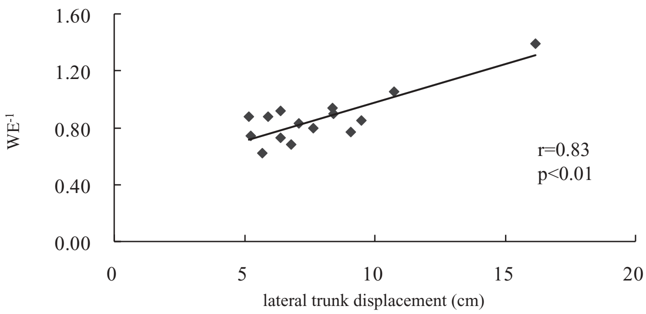

Fig. 3. Correlation coefficients between the total internal work done per unit mass and distance walked (WE^{-1}) and lateral trunk displacement in the THA group

Table 3. Correlation coefficients between the mechanical efficiency of walking (WE^{-1}) and gait speed and lateral displacement of the trunk, pelvis, and COG

Group	Gait speed	LTD	LPD	LCOG
THA (*n* = 15)	–0.32	0.83**	0.16	0.54*
Control (*n* = 14)	0.25	0.52	0.46	0.55*

LTD, amplitude of lateral trunk displacement; LPD, amplitude of lateral pelvic displacement; LCOG, lateral displacement of the center of gravity
$*P < 0.05$; $**P < 0.01$

Discussion

The present study clearly showed that patients during the early postoperative period following THA had significantly reduced gait speed, increased amplitude of LTD, and reduced walking efficiency when compared with healthy persons.

Patients with THA often demonstrate abnormal movement in the trunk or pelvis when walking to compensate hip impairments (e.g., hip abductor weakness, limited range of motion). The extent of the abnormal movement is believed to reflect the degree of hip impairment. In the present study, the THA patients had reduced hip abductor strength as part of their hip impairment. LTD values of the patients were significantly greater than those of the control group, whereas no significant difference was found in LPD values between the two groups. These results were consistent with those reported by Perron et al.[3] Probably the lateral bending of the trunk toward the stance limb with the stabilized pelvis compensates the hip abductor weakness during gait.

The LPD values in the two groups in the present study were similar to those reported by others for healthy subjects.[8,11] Similarly, there was no difference in LCOG between the two groups, evaluated from the ground reaction force. This is probably because the body COG lies within or close to the pelvis.

Mechanical energy expenditure reflects patients' functional performance ability.[9,12] In this study, the total internal work done per unit mass and distance walked (WE^{-1}) was calculated as a negative index representing walking efficiency. The WE^{-1} value of the control group in this study was similar to that reported by Iida and Yamamuro,[10] who measured the WE^{-1} value in healthy subjects. The WE^{-1} value of the THA group was 21.4% higher than that of the control group. The results suggest that the THA patients require more energy to progress their body forward in a gait cycle, indicating a lack of walking efficiency. The most important finding of this study was that LTD in patients soon after THA was nominated as a factor that determines WE^{-1}. Fully 72.1% of the variability of walking efficiency was accounted for by the amplitude of LTD. Bennett et al.[13] noted that children with cerebral palsy were mechanically less efficient in their gait compared with those without. Chen et al.[14] also reported that compensatory movements in the gait of poststroke hemiplegic patients, such as pelvic hiking or trunk raising, contribute to increased mechanical energy expenditure. In this study, the trunk compensation strategy for hip abductor weakness in patients soon after THA probably led to increased energy consumption. Identifying the kinematic characteristics resulting in increased energy demand during walking may provide insights for rehabilitation interventions.

The main function of the hip abductors is to provide frontal plane stability to the hip during the single supporting period in a gait cycle.[15] However, hip muscle weakness and lateral bending of the trunk toward the affected side during walking persist 6 months to 3 years after THA.[1–4,16,17] It has been reported that the hip abductor weakness of the affected side is a major risk factor causing some complications of THA surgery (e.g., joint instability, loosening)[16,18,19] and pathological changes in the knee and ankle joints.[5,6] In addition, weakness of hip and knee muscles reduces a person's ability to manage stairs or slopes and to utilize public transport. Therefore, continual practice during exercise programs starting just after THA surgery, especially those including strengthening exercise of the hip abductors, is important for patients to prevent complications and to improve walking performance and efficiency.

This study has several limitations. The kinetic analysis was made mainly on the frontal plane. More detailed three-dimensional evaluations would provide the basis for a sophisticated exercise program for patients after THA surgery. Especially, differential function of each abductor muscle should be carefully studied during a gait cycle, taking into account the tilt and location of the pelvis relative to a perpendicular line passing the COG.

Another shortcoming of the study is a lack of long-term follow-up. Iida and Yamamuro[10] reported that the pattern of the COG movement of patients with THA and their gait efficiency recovered to a level almost equal to that in healthy people at 18 months after surgery. To clarify the recovery process and investigate the role of physical therapy in the process, we must analyze the kinematic and kinetic data obtained longitudinally from patients with longer follow-up.

In this study, the average gait speed without any assistive device in early postoperative patients of THA was 26.6% slower than that of healthy people. The gait speed was not correlated with walking efficiency (r = –0.32, $P > 0.05$). Many articles[1–4] have reported reduced gait speed in THA patients even after a long follow-up, and Miki et al.[20] reported normalization of walking velocity at 1 year after unilateral THA. As the present study investigated relatively young patients with unilateral disease and surgery, with the possibility of eventually recovering gait speed, further longitudinal study is desirable.

Conclusion

Trunk compensation strategy for hip abductor muscle weakness in patients soon after THA results in reduced walking efficiency. Therefore, an exercise program starting just after THA that emphasizes strengthening exercises for hip abductors is important for patients to improve walking efficiency and to reduce the occurrence of some complications of THA surgery.

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

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