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Gait asymmetry following an anterior and anterolateral approach to total hip arthroplasty

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ABSTRACT

Background: Patients with osteoarthritis of the hip demonstrate a limp while ambulating, and persistent asymmetric limb loading following unilateral total hip arthroplasty might induce further complications in the affected and contralateral limbs. The purpose of this study was to investigate pre- to postsurgical changes in gait symmetry in patients receiving either an anterior or anterolateral hip replacement.
Methods: Three-dimensional kinematic and kinetic gait analyses were performed on 12 patients undergoing anterior surgery, 11 patients undergoing anterolateral surgery and 10 age-matched controls while level walking. A two-way mixed model analysis of variance with repeated measures was utilized to determine differences in symmetry indices and pelvic obliquity between groups and across time.
Findings: At presurgery, greater single limb support time and step length asymmetry was demonstrated by both patient groups when compared to controls. While the anterior hip replacement patients demonstrated greater improvement in gait symmetry by 6 weeks postsurgery, both patient groups approached control levels by 16 weeks postsurgery. No significant differences were seen between patient groups for pelvic obliquity, limb loading or temporal-distance symmetry at any time point.
Interpretation: Patients undergoing either anterior or anterolateral hip replacement enhanced their gait symmetry by 16 weeks following surgery. Improvement in gait symmetry at 6 weeks postsurgery, as compared to presurgery, was detected in patients undergoing anterior hip replacement. However, no such improvement was observed in patients receiving the anterolateral approach. Findings of this study highlight the potential impact of surgical approach on short-term changes in gait asymmetry.

1. Introduction

Over the last four decades, total hip arthroplasty (THA) has emerged as one of the most frequently performed and successful reconstructive procedures in orthopedic surgery (Kennon et al., 2003). In 2003 alone, more than 200,000 THA surgeries were performed in the United States (Zhan et al., 2007), with the cost of each replacement exceeding $20,000 (Lavernia et al., 1995). Two thirds of all THA patients are over 65 years old (Crawford and Murray, 1997), while half are considered obese (Chan and Villar, 1996). Since both the number of Americans over the age of 65 and the number of Americans considered obese in the United States have increased significantly in the last decade (Ogden et al., 2004), the number of THAs performed each year has increased. While THA is considered to be a cost effective procedure for reducing pain and improving joint function, with approximately 85% of implants functioning after 20 years (Crawford and Murray, 1997; Irving, 2004), lingering antalgic gait patterns are exhibited by patients following THA (McCrory et al., 2001). Though limping is common for THA patients at presurgery, persistent asymmetric limb loading following unilateral THA might induce overloading of the non-operated hip joint, and lead to osteoarthritis (OA) of the contralateral limb or increase the risk of falls (Talis et al., 2008).

Due to pain and weakness in the involved hip, patients undergoing THA often demonstrate a pattern of prominent limping or asymmetries in their gait (Cichy et al., 2008). Prior to a posterior approach THA, patients demonstrated asymmetry in hip, knee and pelvic motion, with persistent asymmetries of the hip joint up to 12 months postsurgery (Miki et al., 2004). Using a symmetry index, it was found that anterolateral and posterolateral patients were best categorized through asymmetries in their hip and trunk motion at 6 months postsurgery (Madsen et al., 2004). While static Trendelenburg tests can provide indications of hip joint dysfunction (Hardcastle and Nade, 1985; Pai, 1996), utilization of gait analysis provides functional assessment of joint asymmetries and pelvic obliquity.

For the anterolateral approach THA, an incision is centered over the greater trochanter and lateral to the tensor fascia latae. The anterior one-third of the gluteus medius and minimus are detached

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from the greater trochanter to allow for femoral dislocation and adequate exposure to the joint, with a capsulectomy performed (Hardinge, 1982; Irving, 2004; Mulliken et al., 1998). At closure, the gluteus medius and minimus tendons are reattached to their insertions. During surgery, external hip rotator muscles were not detached. This approach allows for optimal implant positioning and leg length correction (Hardinge, 1982), though it has been associated with delayed abductor muscle recovery, increased frequency of hip dislocation and the development of a limp (Masonis and Bourne, 2002; Baker and Bitounis, 1989).

The anterior approach to THA, as performed in this study, utilizes a PROfx table (Orthopedic Systems Inc., Union City, CA, USA) with the patient in the supine position (Matta et al., 2005). An incision is made lateral and distal to the anterior superior iliac spine, slightly anterior to the greater trochanter. Dissections are made to the medial aspect of the tensor fascia lata, with the sartorius and rectus femoris retracted medially in order to access the joint (Matta et al., 2005). The goals of this surgery are to reduce trauma to abductor muscles, and possibly reduce short-term limping. The anterior approach has been shown to have low dislocation rates (Siguier et al., 2004) and reduced trauma to abductor muscles (Matta et al., 2005; Kennon et al., 2003), though development of a limp or asymmetrical gait has not been investigated in this population.

It is unknown whether differences in surgical approach might impact the amount of gait asymmetry following THA. Therefore, the purpose of this study was to examine which surgical approach, anterolateral or anterior, minimized short-term limping in THA patients. As shown previously, due to OA of the hip for all patients, we expected that prior to THA, both the anterolateral and anterior groups would display asymmetric gait patterns as demonstrated by stride length, single limb support time and pelvic obliquity when compared with the control group. Following surgery, due to trauma of the hip abductors for the anterolateral approach, it was hypothesized that compared to the anterior group, the anterolateral group would display greater asymmetry in gait patterns both 6 and 16 weeks postsurgery.

2. Methods

Twenty three patients, including 12 patients undergoing anterior THA (mean age (SD): 56.9 (3.4) years, BMI (SD): 32.0 (5.1) kg/m^2, 7 males) and 11 patients undergoing anterolateral THA (mean age (SD) = 57.0 (7.3) years, BMI (SD): 31.1 (4.1) kg/m^2, 9 males) were recruited from the practices of two joint replacement surgeons at the Slocum Center (Eugene, OR, USA). The anterolateral patients were recruited from one surgeon (DKC) who has utilized this approach for 3000 primary total hips, and the anterior patients were recruited from one surgeon (BAJ) who has used this approach for 300 hips. All patients had unilateral OA of the hip, with no prior lower limb surgery, neurological or musculoskeletal deficits. Ten age-matched control subjects (mean age (SD): 59.9 (5.3) years, BMI (SD): 26.3 (3.9) kg/m^2, 5 males) with no lower limb joint surgery, arthritis or vertigo were recruited from the surrounding community. Prior to testing, all controls and patients provided signed consent to the protocol as approved by the Institutional Review Board.

Patients from both THA groups received uncemented Zimmer hip implants which consisted of an acetabular component with an irradiated polyethylene liner (Trilogy Acetabular component; Zimmer Inc, Warsaw, IN, USA) and a femoral stem (Alloclassic SL Stem or Fiber Metal Taper; Zimmer Inc) and metal head component (32 mm Cobalt/Chrome or 36 mm Cobalt/Chrome; Zimmer Inc). Left and right leg lengths were similar for the anterolateral (91.6 cm and 91.9 cm, respectively) and anterior (90.7 cm and 90.8 cm, respectively) groups at presurgery and postsurgery. All patients underwent the same rehabilitation protocol with a hospital therapist starting the day of surgery, and being followed by the same outpatient therapist at 2, 6 and 16 weeks. Patients began weight bearing with crutches immediately after surgery, with weight bearing on the operated extremity as tolerated. By 3–4 weeks postsurgery, patients switched to a cane and progressed to full weight bearing between 6 and 12 weeks postsurgery. Active abduction against gravity was started at 6 weeks postsurgery with patients no longer using crutches by 16 weeks postsurgery. Gait analysis for THA patients occurred at presurgery and 6 and 16 weeks postsurgery. Controls were tested twice within 1 month to account for any interexaminer reliability (two examiners) or intrasubject repeatability.

Subjects were asked to walk at a self-selected pace across a 10 m walkway during all visits. A minimum of 5 walking trials were performed, with additional trials performed depending on the pain tolerance of the subjects. Three-dimensional marker trajectories of 29 markers placed on bony landmarks (Chou et al., 2003) were captured at 60 Hz using an 8-camera motion analysis system (Motion Analysis Corp, Santa Rosa, CA, USA). Motion data were filtered using a fourth order low-pass Butterworth filter, with a cut-off frequency of 8 Hz. Ground reaction forces (GRF) of both feet were collected at 960 Hz with two force plates (Advanced Mechanical Technology, Inc, Newton, MA, USA) placed in series along the walkway.

Motion and GRF data from a single gait stride of each trial were analyzed. Peak magnitudes of the vertical GRF at the early and late stance phase of both limbs were identified and compared. Gait velocity was determined by the position and time change of the whole-body center of mass (Lugade et al., 2008). Average step width was calculated as the mediolateral distance between ankle joint centers at heel strike of each foot. Step length was calculated as the distance between heel markers at heel strike, with right step length defined at right heel strike and left step length determined at left heel strike. Single limb support time was defined as the percent of gait cycle each limb supported the body on its own. The symmetry index (SI) was determined as previously described (Zifchock et al., 2008) using the formula:

$$SI = \frac{(X_{\mathrm{involved}} - X_{\mathrm{uninvolved}})}{X_{\mathrm{uninvolved}}} \times 100\% \quad (1)$$

where X_{involved} and $X_{\mathrm{uninvolved}}$ are randomly assigned for controls (McCrory et al., 2001). A value closer to 0 would indicate symmetry between limbs, while larger positive and negative values would demonstrate a greater asymmetry towards the involved or uninvolved limb, respectively.

Pelvic obliquity was calculated throughout gait as the frontal plane angle of the pelvis in relation to the global coordinate system (Fig. 1) (Madsen et al., 2004). For analysis, the pelvic obliquity angle at midstance (the point where the GRF is a trough at approximately 30% of the gait cycle) was examined, as this is the point at which the involved limb fully supports the whole body. Positive values of pelvic obliquity indicated a rise in the pelvis on the involved side, while negative values indicated a drop in the pelvis on the involved side.

The effect of surgical approach on symmetry indices and pelvic obliquity was determined using a two-way mixed model ANOVA with repeated measures with group as the between-subjects factor and time as the within-subjects factor. Group and time comparisons were performed using Bonferroni post-hoc analysis. Statistical analysis was performed using SPSS 14.0 (SPSS Inc., Chicago, IL, USA).

3. Results

Prior to surgery, THA groups demonstrated greater limb asymmetry in step length and single limb support time when compared to the control group, although slight differences were observed in GRF symmetry (Table 1). An approximately 5% reduced single limb support time and 4 cm increased step length was seen in the surgical limb among both THA groups, when compared to the non-surgical

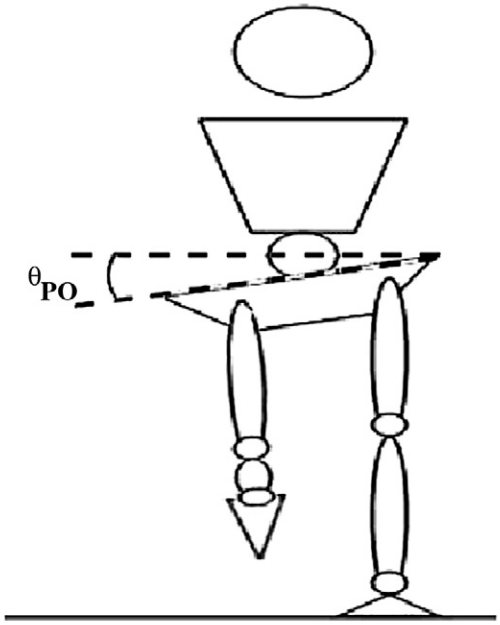

Fig. 1. Frontal plane pelvic obliquity (θ_{PO}) measured as the angle of the right and left ASIS markers to the horizontal. A positive pelvic obliquity indicates a drop in the contralateral hip while a negative pelvic obliquity signifies a rise in the contralateral hip.

limb (Fig. 2). For the anterior and anterolateral THA groups, presurgical asymmetry was much greater than controls, with an approximately 11–12% greater asymmetry for single limb support time (P = .013 and P = .026, respectively). Compared to the anterior THA group, no differences were seen for single limb support time (P = .089) or step length symmetry (P = .621) among the anterolateral THA groups at presurgery. Similarities were seen among all other variables between the surgical groups at this time point. Slower gait velocity and larger step width were observed for both anterior (P = .002 and P = .007, respectively) and anterolateral THA (P = .051 and P = .035, respectively) groups at presurgery when compared to the control group (Table 2).

Greater asymmetry was observed among anterolateral patients at 6 weeks postsurgery, compared to anterior THA patients. Improvement in single limb support time symmetry was observed among anterior THA patients by 6 weeks postsurgery (P = .009) when compared to presurgery, while no such improvement was seen among anterolateral patients (P = .101) (Table 1). Anterior THA patients approached the level of controls for both step length (P = .281) and single limb support time (P = .633), though they did not approach controls for the first peak GRF symmetry (P = 0.033). At this time, the anterolateral THA patients showed greater asymmetry for step length (P = .018), when compared to controls. No differences in gait velocity (P = .219) or step width (P = .197) were seen between the two THA groups at 6 weeks postsurgery.

By 16 weeks postsurgery, both anterior and anterolateral groups demonstrated increased single limb support time symmetry (P < .001 and P = .002, respectively) and gait velocity (P < .001 and P = .017, respectively), when compared to presurgery, though no change was seen for pelvic obliquity or step width. The anterior THA group also showed increased step length and second peak GRF symmetry (Fig. 3) (P = .017 and P = 0.029, respectively) when compared to presurgery. While the anterolateral THA group demonstrated improved step length symmetry at 16 weeks postsurgery (P = .044) when compared to 6 weeks postsurgery, this group continued to demonstrate greater asymmetry in step length when compared to controls at 16 weeks postsurgery (P = 0.012). While group differences were not seen for GRF symmetry, both THA groups demonstrated improvement in the vertical GRF from presurgery to postsurgery (Fig. 3). A trend of greater uninvolved limb GRF forces were evident at presurgery when compared to the involved limb, with equal vertical GRF forces for both limbs by 16 weeks postsurgery.

Throughout all visits, including presurgery and postsurgery, greater pelvic drop at midstance of the affected limb was demonstrated by both the anterior THA (P = 0.002) and anterolateral THA (P = 0.032) groups, when compared to controls (Table 3). No differences in pelvic obliquity were witnessed between THA groups for the affected limb (P = .326). No group or time differences were demonstrated among the unaffected limb for pelvic obliquity at midstance.

4. Discussion

In this study, it was believed that patients who were to undergo either the anterior or anterolateral approach to THA would display asymmetric gait patterns as demonstrated by stride length, single limb support time and pelvic obliquity at presurgery. Due to trauma of the hip abductors, we hypothesized that the anterolateral group

Table 1
Symmetry index (SD) between limbs.

Variable	Control[a]	Anterior THA	Anterolateral THA	P^{b}	$P^{c,d}$
Single limb support					
Presurgery	−1.1 (1.8)	−11.9 (9.5)	−10.9 (13.3)	.039[b]	.190[c]
6 weeks postsurgery		−3.2 (6.3)	−5.4 (16.5)		
16 weeks postsurgery		0.6 (2.5)	−2.1 (6.4)		<.001[d]
Step length					
Presurgery	0.7 (2.7)	10.3 (12.3)	8.3 (10.1)	.216[b]	.007[c]
6 weeks postsurgery		6.3 (7.4)	13.9 (19.2)		
16 weeks postsurgery		2.9 (4.7)	7.5 (8.6)		.037[d]
GRF at weight acceptance					
Presurgery	0.1 (2.9)	−6.0 (12.7)	−7.2 (8.2)	.706[b]	.089[c]
6 weeks postsurgery		−5.5 (6.5)	−4.8 (6.4)		
16 weeks postsurgery		−3.6 (4.6)	−1.9 (7.8)		.271[d]
GRF at push off					
Presurgery	0.5 (4.2)	−4.4 (7.5)	−1.4 (5.3)	.049[b]	.267[c]
6 weeks postsurgery		−1.8 (6.8)	−3.9 (5.4)		
16 weeks postsurgery		−0.8 (5.0)	−4.6 (6.5)		.951[d]

SD = standard deviation.
[a] Control values averaged across 2 visits one month apart.
[b] Represents group by time interaction.
[c] Represents group effects.
[d] Represents time effects.

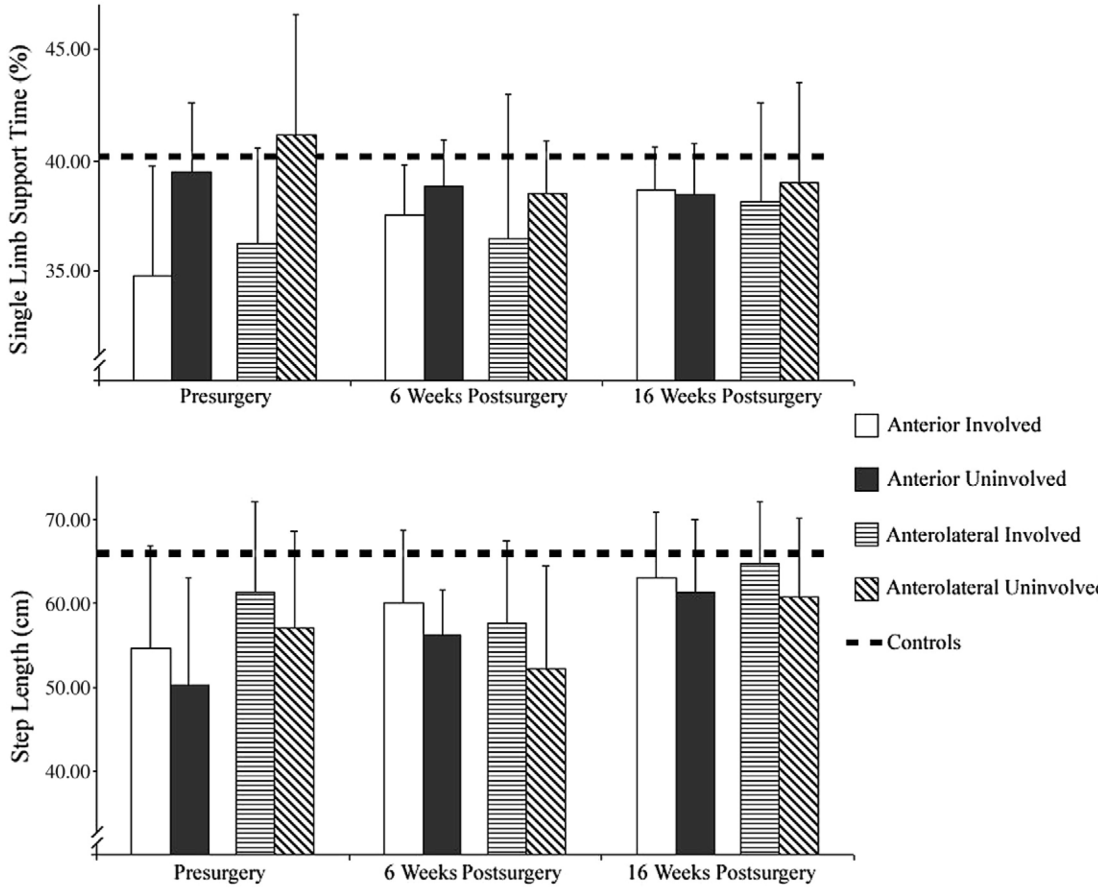

Fig. 2. Group average and standard deviation for single limb support time and step length for surgical and unaffected limbs across visit. The dashed line indicates the average value for controls (single limb support time (SD) = 40.4 (2.3) % and step length (SD) = 66.6 (5.6) cm).

would display greater asymmetry in gait patterns following surgery. While both the anterior and anterolateral THA groups continued to demonstrate differences in symmetry and pelvic obliquity from the control group at 6 weeks postsurgery, the anterior group demonstrated improvement in symmetry at 6 weeks postsurgery when compared to presurgery. No such improvement was seen among the anterolateral THA group. Both groups approached the level of controls in temporal distance and symmetry measures at 16 weeks postsurgery, when compared to presurgery.

Prior to THA, both surgical groups displayed asymmetric gait patterns, as witnessed by differences in step length, single limb support time and pelvic obliquity when compared to controls. These gait asymmetries may be due to adaptive compensatory behaviors and pain caused by OA during ambulation. Pain and loading were shown to be interrelated among patients with OA, with gait adaptations possibly leading to clinical implications such as muscle atrophy, bone loss and pain in other joints (Hurwitz et al., 1997). Asymmetric knee loading among unilateral end-stage hip OA subjects was also shown to indicate a prolonged gait adaptation which could affect other lower limb joints as well as the contralateral limb (Shakoor et al., 2003).

Greater vertical GRF loading was seen for a majority of the THA patients in the unaffected limb, when compared to the affected limb at presurgery (Fig. 3). Reduced loading patterns on the affected limb could be indicative of reduced bone growth and slow recovery, with unknown effects on the increasingly loaded unaffected limb (Madsen et al., 2004). The use of GRF has also been shown in past studies to effectively quantify antalgic gait among hip arthroplasty patients

Table 2
Temporal-distance gait measures (SD).

	Control[a]	Anterior THA	Anterolateral THA	*P*[b]	*P*[c,d]
Gait velocity (m/s)					
Presurgery	1.28 (0.17)	0.94 (0.26)	1.07 (0.25)	<.001[b]	.030[c]
6 weeks postsurgery		1.08 (0.20)	0.97 (0.26)		
16 weeks postsurgery		1.19 (0.17)	1.17 (0.17)		<.001[d]
Step width (cm)					
Presurgery	9.76 (1.9)	14.5 (4.9)	13.4 (3.8)	.039[b]	.001[c]
6 weeks postsurgery		13.4 (2.7)	14.9 (3.4)		
16 weeks postsurgery		13.0 (3.1)	12.3 (3.0)		.151[d]

SD = standard deviation.
[a] Control values averaged across 2 visits one month apart.
[b] Represents group by time interaction.
[c] Represents group effects.
[d] Represents time effects.

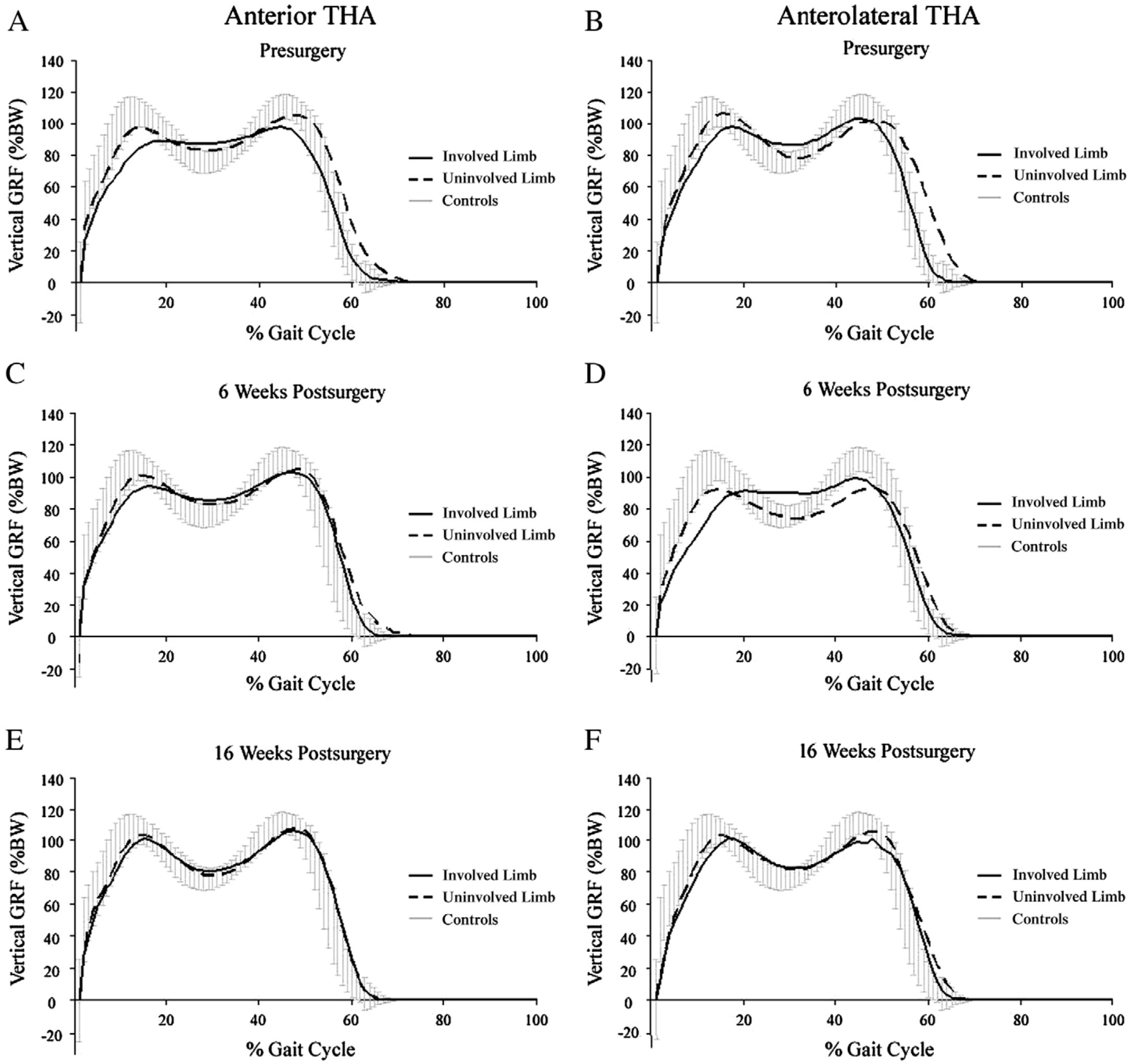

Fig. 3. Group averages for THA patients for vertical ground reaction forces across a gait cycle. The vertical bars represent ±1SD values for controls.

(McCrory et al., 2001). While the use of GRF in the anterior–posterior and medial–lateral direction has demonstrated asymmetries among normal human gait, it is a reasonable assumption that normal gait demonstrates vertical GRF symmetry (Herzog et al., 1989).

Step length asymmetry was still observed among anterolateral patients at 6 weeks postsurgery. Reduced leg progression of the unaffected limb among this patient group may be due to weakness in the hip abductor muscle strength of the supporting (affected) limb. Such abductor strength weakness has been reported previously (Perron et al., 2000), with both anterior and anterolateral patients demonstrating weaker isometric hip abductor strength and reduced hip range of motion at presurgery and up to 16 weeks postsurgery, when compared to controls (Klausmeier et al., 2009). Klausmeier and colleagues found that the anterior THA patients demonstrated a continuous increase in hip abductor strength postsurgery, while the anterolateral group dropped below preoperative levels at 6 weeks postsurgery. The use of pelvic obliquity to determine such muscle weakness did not discriminate between the anterior and anterolateral THA groups in this study, though both patient groups did demonstrate an approximately one degree drop in the pelvis at midstance of the affected limb. These results were similar to those reported by Madsen et al. (2004), who believe other factors, such as individual differences in trunk inclination or scarring of the tissues surrounding the hip, might affect how a patient maintains hip obliquity in the frontal plane.

Both THA groups approached the level of controls by 16 weeks postsurgery for temporal-distance symmetry indices, though differences were still found for pelvic obliquity and step width. These results are in opposition to Madsen et al. (2004) who found that a majority of THA patients had not returned to normal for gait symmetry even by 6 months postsurgery. It is possible that our cohort of individuals demonstrated faster recovery of gait symmetry due to differences in rehabilitation, surgical procedure and activity

Table 3
Pelvic obliquity at midstance (SD).

	Control[a]	Anterior THA	Anterolateral THA	P[b]	P[c,d]
Affected limb (deg)					
Presurgery		−1.16 (3.82)	−0.99 (2.82)	.808[b]	.008[c]
6 weeks postsurgery		−1.82 (1.75)	−0.66 (2.45)		
16 weeks postsurgery		−0.90 (3.26)	0.07 (1.82)		.481[d]
Unaffected limb (deg)	1.27 (0.86)				
Presurgery		−0.72 (3.10)	0.18 (2.49)	.448[b]	.498[c]
6 weeks postsurgery		1.07 (2.29)	0.78 (3.12)		.248[d]
16 weeks postsurgery		1.23 (3.03)	0.88 (2.29)		

SD = standard deviation. Negative values represent pelvic drop of the stance limb.
[a] Control values averaged across both limbs and visits.
[b] Represents group by time interaction.
[c] Represents group effects.
[d] Represents time effects.

level. In addition, patients in this study were approximately 5 years younger and possibly undertaking a more active lifestyle. Such differences might explain the faster improvement in gait symmetry.

There are a few limitations to this study. First, though a majority of THA patients in the United States are women, and aged over 65 (Zhan et al., 2007), THA patients who volunteered for this study were mostly male with an average age of 58 years. While a greater sample size could provide statistically greater power, we were still able to detect differences in symmetry between THA groups and controls. Second, our control subjects had a smaller BMI than THA patients. Past studies have demonstrated that a high BMI can be a risk factor for OA and subsequent THA (Karlson et al., 2003), with the BMI values among our THA patients and controls being consistent with typically reported values (Namba et al., 2005; Ogden et al., 2004). Finally, only short-term recovery patterns were analyzed, though several studies have demonstrated persistent differences up to one year following surgery (Foucher et al., 2007; Perron et al., 2000). A better understanding of short-term gait patterns following THA would allow for proper postoperative rehabilitation and faster recovery.

In conclusion, the anterior THA group demonstrated improvement in gait symmetry at 6 weeks postsurgery when compared to presurgery. Although no such improvement was observed among the anterolateral THA group, both THA groups approached the level of controls by 16 weeks postsurgery with reduced asymmetries between their surgical and uninvolved limbs. Findings of this study highlight the potential impact of surgical approaches on short-term changes in gait asymmetry.

Conflict of interest statement

Each author confirms that he or she has no potential conflict of interest (e.g., consultancies, stock ownership, equity interests, patent/licensing arrangements, etc.) related to the manuscript.

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