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Stephen Petis

James Howard

Brent Lanting

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Stephen Petis, MD
James Howard, MD
Brent Lanting, MD
Ian Jones, MA
Trevor Birmingham, PT, PhD
Edward Vasarhelyi, MD

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Correspondence to:
S. Petis
Unit 2
960 Bitterbush Crescent
London ON N6H 0G1
stephen.petis@gmail.com

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Background: The choice of surgical approach for total hip arthroplasty (THA) remains a contentious issue with regards to clinical outcome optimization and restoring patient function. The purpose of this study was to determine the impact of surgical approach for THA on quantitative gait analysis.

Methods: Patients undergoing THA for primary osteoarthritis of the hip were assigned to 1 of 3 surgical approaches: anterior, posterior and lateral. Standardized implants were used at the time of surgery. Three-dimensional gait analysis was performed preoperatively and at 6 and 12 weeks postoperatively. At each time point, we compared temporal parameters, kinematics and kinetics.

Results: We included 30 patients in our analysis (10 anterior, 10 posterior, and 10 lateral). The groups were similar with respect to age ($p = 0.27$), body mass index ($p = 0.16$), and Charlson Comorbidity Index score ($p = 0.66$). Temporal parameters were similar among the groups at all time points. The lateral cohort had higher pelvic tilt during stance on the affected leg than the anterior cohort at 6 weeks ($p = 0.041$). Affected leg ipsilateral trunk lean during stance was higher in the lateral group than in the other cohorts at 6 weeks ($p = 0.008$) and 12 weeks ($p = 0.040$). The anterior and posterior groups showed increased external rotation at 6 weeks ($p = 0.003$) and 12 weeks ($p = 0.012$) compared with the lateral group.

Conclusion: Temporal gait parameters were similar following THA for all approaches. Differences in gait kinematics and kinetics exist; however, given the small absolute differences, the clinical importance of these changes remains undetermined.

Contexte : Le choix de l'approche chirurgicale pour la pose d'une prothèse totale de la hanche (PTH) ne fait pas l'unanimité sur le plan de l'optimisation des résultats cliniques et du rétablissement fonctionnel des patients. Le but de cette étude était de déterminer l'incidence de l'approche choisie sur les résultats de l'analyse quantitative de la démarche.

Méthodes : Les patients qui se font poser une PTH en raison d'une arthrose primaire de la hanche ont été opérés selon l'une des 3 approches suivantes : antérieure, postérieure ou latérale. Des implants standards ont été utilisés pour la chirurgie. Une analyse tridimensionnelle de la démarche a été effectuée avant l'intervention, puis après 6 et 12 semaines. À chaque étape, nous avons comparé les paramètres temporels, cinématiques et cinétiques.

Résultats : Nous avons inclus 30 patients dans notre analyse, soit 10 par approche. Les groupes présentaient des caractéristiques similaires en ce qui concerne l'âge ($p = 0,27$), l'indice de masse corporelle ($p = 0,16$) et l'indice de comorbidité de Charlson ($p = 0,66$). Les paramètres temporels étaient similaires d'un groupe à l'autre à toutes les étapes de l'étude. Six semaines après l'intervention, le groupe opéré selon l'approche latérale présentait une bascule pelvienne à la station debout du côté du membre affecté plus prononcée que le groupe opéré selon l'approche antérieure ($p = 0,041$). Il présentait aussi une inclinaison du tronc du côté de la jambe affectée à la station debout plus marquée que les 2 autres groupes, à 6 semaines ($p = 0,008$) et à 12 semaines ($p = 0,040$). Les groupes opérés selon les approches antérieure et postérieure présentaient une rotation externe accrue à 6 semaines ($p = 0,003$) et à 12 semaines ($p = 0,012$) comparativement au groupe soumis à l'approche latérale.

Conclusion : Après la pose de la PTH, les paramètres temporels de la démarche étaient similaires, peu importe l'approche utilisée. Des différences cinématiques et cinétiques ont été observées à la démarche; toutefois, compte tenu de la faible valeur absolue de ces différences, leur portée clinique reste indéterminée.

Total hip arthroplasty (THA) is the hallmark treatment modality for severe arthritis of the hip. The procedure provides excellent patient-reported outcomes and pain mitigation, and is cost-effective when compared with nonoperative care.[1,2] However, it is important for surgeons and patients to understand the quantitative, biomechanical changes that occur following reconstructive procedures, such as THA. A useful instrument to capture these changes is gait analysis. Validated and reproducible, gait analysis has been used extensively to detect changes in gait mechanics that occur following THA.[3–5]

There is ongoing interest on the impact of various surgical approaches to the hip for THA gait mechanics. Commonly used surgical approaches for THA include the lateral, posterior and anterior approaches. In Canada, approximately 60% of surgeons use a lateral hip approach, 34% a posterior hip approach and fewer than 5% an anterior approach.[6] The lateral approach involves surgical release and repair of the abductor musculature.[7] The potential functional implications of violating the abductors is unclear but may negatively impact gait mechanics, including a Trendelenburg gait or a compensatory contralateral pelvic tilt.[8] Conversely, the posterior approach involves release and repair of the short external rotators, which can result in changes to rotatory kinetics.[9] Finally, the anterior approach uses an internervous plane between sartorius and tensor fascia latae that attempts to spare the surrounding hip musculature.[10] The presumed advantage of this approach is avoiding the aforementioned deficits seen with the lateral and posterior approaches. However, cadaveric studies have suggested that abductor muscle damage is observed during a THA using an anterior approach, and surgical releases (i.e., piriformis, tensor fascia latae) are sometimes required to improve exposure during preparation of the femur and acetabulum.[6,11]

Previous studies have elucidated differences in gait analysis between the surgical approaches.[3,8,9,12] Limitations in study design that hamper the ability to interpret those results include retrospective analyses, lack of standardized implants, small sample sizes and heterogeneity in time points used for follow-up.

The purpose of the present study was to determine the impact of surgical approach on gait mechanics following THA. We were particularly interested in the effect of approach on postoperative pelvic tilt and abductor function, as it was unclear whether there is a quantifiable change in these gait parameters following THA. Our hypothesis was that there would be no significant differences in temporal distance, kinematic, or kinetic parameters following THA between the 3 different surgical approaches at early follow-up.

Methods

Patients were distributed through our institution's centralized arthroplasty intake system and then recruited from the clinic of 1 of 3 fellowship-trained arthroplasty surgeons. Patients were included in the study if they had primary osteoarthritis of the hip; consented for treatment with a THA through an anterior, posterior, or lateral approach; were 19 years of age or older; and did not meet any of the exclusion criteria. The exclusion criteria were body mass index (BMI) greater than 40; diagnosis other than primary osteoarthritis, dementia, or other cognitive disorders; prior hip surgery; cemented THA; simultaneous bilateral THA; cases performed by trainees; use of implants other than those standardized for the study; inadequate understanding of the English language; and inability to complete the gait analysis testing.

We recorded patient demographic characteristics, including age, sex, BMI and age-adjusted Charlson Comorbidity Index score. Each patient was assigned a Charnley class based on history, clinical examination and radiographic images.

Our institutional review board approved our study protocol before we began enrolling patients in the study.

Procedure

Each of the 3 surgeons performed only 1 of the 3 surgical approaches (anterior, posterior, or lateral). Each surgeon had completed more than 100 cases using their respective approach during the course of their training and clinical practice. A specialized operating room table (Hana fracture table, Mizuho OSI) with intraoperative fluoroscopy was used for the anterior approach. The posterior and lateral approaches were performed on a conventional operating room table with the patient in the lateral decubitus position. The posterior approach was completed with an anatomic repair of the short external rotators and joint capsule to the greater trochanter. The lateral approach was performed based on the technique described by Hardinge.[7] A detailed outline of the surgical technique we use for each approach has been published previously.[6] Each patient received standardized implants at the time of the procedure: a hydroxyapatite-coated, cementless femoral stem (Corail stem, DePuy Orthopaedics Inc.), a cementless acetabular cup (Pinnacle Sector II acetabular cup, DePuy Orthopaedics Inc.), a highly cross-linked polyethylene liner (AltrX polyethylene liner, DePuy Orthopaedics Inc.), and a cobalt chrome femoral head (Articul/eze cobalt chrome, DePuy Orthopaedics Inc.). Cancellous screws

(DePuy Orthopaedics Inc.) were inserted to augment acetabular fixation at the surgeon's discretion.

Postoperatively, all patients received 24 hours of antibiotics. Prophylaxis against deep vein thrombosis was administered. Analgesia was managed by our institution's acute pain service. All patients were permitted to weight-bear as tolerated and use a gait aid as needed under the guidance of physiotherapy. Patients were discharged once they met the criteria of our institution's discharge pathway. Outpatient physical therapy was prescribed at the discretion of the surgeon based on patients' progress.

Gait analysis

Patients underwent 3-dimensional gait analysis preoperatively and at 6 and 12 weeks following THA. Twenty-two reflective markers from a modified Helen Hayes marker set were placed on each patient. In addition, we placed 4 markers bilaterally over the medial knee joint line and medial malleolus during an initial static standing trial. Body mass, marker orientation and positions of joint centres of rotation for the knee and ankle were determined. We had the patients complete 2 additional dynamic trials of straight leg swing to determine hip joint centres of rotation. We removed the 4 additional markers before having the patient walk.

Patients then walked across an 8 m walkway at their own pace, without walking aids. All gait analyses were conducted barefoot to negate the potentially confounding effect of shoe type on walking biomechanics. Participants completed a minimum of 12 walking trials to allow for at least 6 clean force plate strikes for each lower limb. We subsequently analyzed 5 trials per limb.

We used an 11-camera, high-resolution motion capture system (Motion Analysis Corporation) operating at 60 Hz to capture temporal distance parameters (gait velocity, step length, stride length) and joint kinematics (hip joint angles, pelvic tilt, lateral trunk lean).[13] A floor-embedded force platform (Model A-6–7, Advanced Mechanical Technology Incorporated) recorded ground reaction forces at 600 Hz, allowing for the calculation of centre of pressure and joint kinetics. External moments about the hip were calculated using inverse dynamics (Orthotrak 6.61, Motion Analysis Corporation). Temporal distance measures, peak hip joint angles, contralateral pelvic tilt, ipsilateral trunk lean and joint moments were compared among the groups.

Statistical analysis

Our sample size determination was based on results published by Varin and colleagues,[3] who reported an effect size of 1.25 for postoperative contralateral pelvic tilt comparing the anterior and lateral approach. Using an effect size of 1.2, α of 0.05 and power of 0.80, we determined that 10 patients were required in each group.

We assessed demographic characteristics using descriptive statistics, including frequencies, means and standard deviations. Categorical variables were tested using cross-tabulation with the Pearson χ^2 test. Variables from the gait analysis were tested for significance using parametric analysis of variance (ANOVA) or nonparametric (Kruskal–Wallis) testing, depending on the distribution of the variable. We performed post hoc testing using a Scheffé test or Mann–Whitney *U* test when appropriate. We considered results to be statistically significant at $p < 0.05$. We used SPSS software version 23 (SPSS Inc.) for all analyses.

Results

A total of 67 patients were approached for study involvement to acquire the necessary 10 patients per surgical approach. All cohorts had complete preoperative, 6- and 12-week gait analyses (Fig. 1). There were no significant differences in patient demographic characteristics between the groups (Table 1).

There were no significant differences in temporal distance parameters between the groups at any of the time points (Table 2). All groups experienced significant improvements in step length, stride length and gait velocity following THA.

Contralateral pelvic tilt was significantly greater in the lateral than in the anterior cohort at 6 weeks postoperatively ($p = 0.041$). This finding was no longer significant at 12 weeks. Preoperatively, there was a significant difference in ipsilateral trunk lean between the anterior and posterior approach groups ($p = 0.022$). However, there was no significant trunk lean difference between these 2 cohorts at 6 or 12 weeks postoperatively. Conversely, the anterior approach group showed significantly less ipsilateral trunk lean than the lateral approach group at 6 weeks ($p = 0.008$) and 12 weeks ($p = 0.040$) postoperatively (Table 3). Other significant findings included an increased peak abduction angle in the lateral versus the anterior approach group at 6 weeks ($p = 0.021$) and differences in peak internal rotation ($p = 0.024$) and external rotation ($p = 0.020$) angles between the anterior and lateral cohorts at 12 weeks (Table 4).

Discussion

The findings in our study reject our hypothesis that there would be no significant differences in gait parameters following THA between the anterior, posterior and lateral approaches. Although temporal parameters were similar at all time points, there were kinematic and kinetic group differences. These statistical differences may be explained by anatomic aberrancies caused by the surgical approaches, but the clinical relevance of the differences is unknown.

Our study was powered to show a difference in contralateral pelvic tilt. This variable is important for a number of reasons. Lateral trunk lean and resulting pelvic tilt may help reduce the external knee adduction moment to offload painful medial compartment knee arthrosis.[13,14] Lateral trunk lean also reduces the joint reaction forces observed by the hip joint with abductor muscle weakness, potentially reducing pain in the presence of hip arthrosis.[15,16] However, Nankaku and colleagues[17] showed that with increasing lateral trunk displacement following THA, gait efficiency declines. Takacs and colleagues[18] also showed that with increasing pelvic tilt, energy expenditure increases. With the aging population, more patients are living with multiple comorbid conditions, such as chronic obstructive pulmonary disease, cardiac disease and renal disease. These comorbidities reduce the capacity of patients to carry out simple activities of daily living (ADL). Therefore, any increase in energy expenditure may reduce independence with ADLs, making subtle changes to pelvic tilt a clinically relevant problem.

Surprisingly, we did not find any difference in peak abduction moments across the cohorts at any time point. As the lateral approach group showed increased pelvic tilt and trunk lean, we expected either an increase in the abductor moment in order to reduce pelvic tilt and trunk lean, or a decrease in the abductor moment due to muscle damage at the time of surgery. As alluded to earlier, it may be that the groups are reducing the abductor moment at the hip to compensate for painful arthrosis at other joints (i.e., medial compartment of the knee). Howell and colleagues[19] suggested that 16%–20% of patients undergoing THA had evidence of abductor mechanism tears. Therefore, it is possible that there are patients in the anterior and posterior cohorts who had abductor insufficiency, thereby making differences between the groups undetectable. This may also explain why there were preoperative differences in trunk lean and peak abduction angle between the groups.

Another significant difference observed between the groups postoperatively was an increased external rotation moment in the anterior and posterior cohorts compared with the lateral approach group. The short external rotators

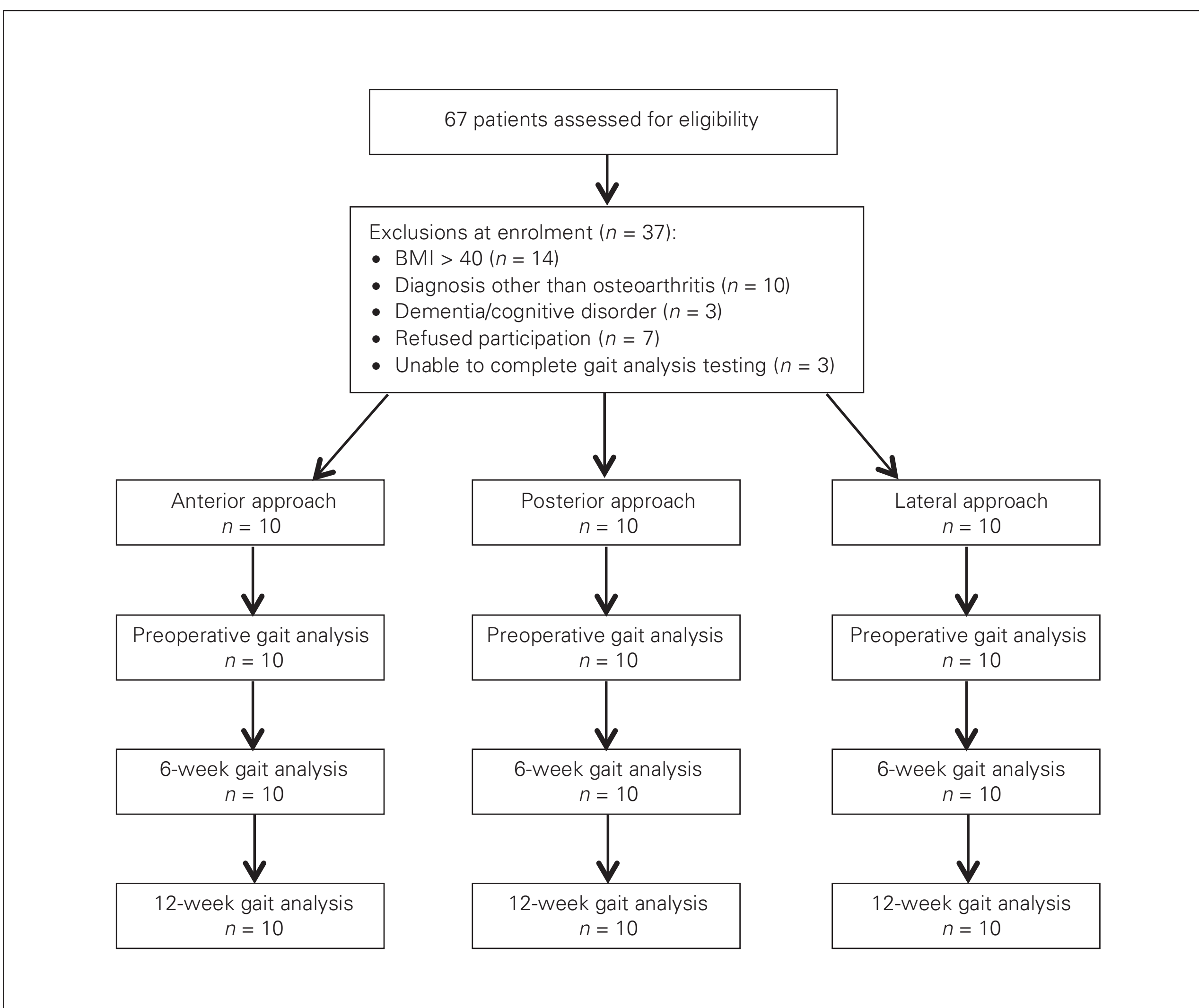

Fig. 1. Flow of patients through the study. BMI = body mass index.

are incised during a posterior approach, and are often released to improve femoral exposure during an anterior approach to the hip.[6,11] The increased external rotation moment may be a compensatory mechanism for the damaged muscles. The gluteus medius and maximus are powerful external rotators during early stance.[20] Recruiting these muscles would prevent internal rotation of the hip, which has a deleterious effect on patello-femoral mechanics of the knee.[21] Alternatively, the gluteus medius is damaged during a lateral approach to the hip. As mentioned previously, this muscle is a powerful external rotator of the hip. Therefore, damage sustained during surgical dissection could cause a decrease in external rotation moments of the hip until the muscle has healed.

Limitations

Our study has limitations. The lack of true randomization may have introduced selection bias on behalf of the surgeon and expectation bias on behalf of the patient. Studies have shown that patients believe minimizing muscle damage is important after major reconstructive surgery, such as THA. Therefore, knowing that an approach potentially is "muscle-sparing" may psychologically prime an individual to be more motivated to achieve earlier mobilization and hasten progress with rehabilitation.[22] It is important to consider this confounding factor across all comparative studies that examine minimally invasive or muscle-sparing, techniques. The addition of an age-, sex- and

Table 1. Patient demographic and clinical characteristics

	Group; mean [range] or no.			
Characteristic	Anterior	Posterior	Lateral	*p* value
Age, yr	70.5 [62–82]	67.7 [66–74]	64.9 [58–73]	0.27
Sex, female:male	6:4	5:5	5:5	0.87
BMI	25.6 [20.0–34.1]	27.6 [19.8–33.7]	29.7 [21.2–39.8]	0.16
Age-adjusted Charlson Comorbidity Index score	3.6 [1–6]	3.1 [1–5]	2.9 [0–6]	0.66
Charnley classification				
A	1	2	3	
B1	5	5	6	
B2	3	1	1	
C	1	2	0	

BMI = body mass index.

Table 2. Summary of temporal distance parameters of gait

	Group; mean [range]			
Parameter	Anterior	Posterior	Lateral	*p* value*
Step length, m				
Preoperative	0.44 [0.25–0.59]	0.53 [0.35–0.67]	0.48 [0.39–0.53	0.89
6 wk	0.51 [0.32–0.62]	0.58 [0.51–0.69]	0.48 [0.31–0.58]	0.18
12 wk	0.52 [0.35–0.63]	0.60 [0.53–0.71]	0.56 [0.43–0.64]	0.19
Stride length, m				
Preoperative	0.86 [0.47–1.13]	1.06 [0.83–1.29]	0.95 [0.76–1.05]	0.08
6 wk	1.00 [0.58–1.22]	1.14 [0.99–1.36]	0.98 [0.66–1.11]	0.19
12 wk	1.02 [0.62–1.26]	1.20 [1.11–1.37]	1.12 [0.91–1.29]	0.15
Gait velocity, m/s				
Preoperative	0.67 [0.30–1.08]	0.86 [0.53–1.06]	0.76 [0.60–0.95]	0.10
6 wk	0.86 [0.50–1.29]	0.98 [0.75–1.15]	0.82 [0.36–0.96]	0.36
12 wk	0.92 [0.41–1.56]	1.09 [0.99–1.33]	1.00 [0.84–1.14]	0.33
Stance phase, %				
Preoperative	65.0 [59.6–71.0]	62.8 [59.5–64.7]	64.2 [60.8–69.2]	0.20
6 wk	64.8 [62.5–68.6]	62.9 [59.5–65.4]	65.1 [60.1–74.8]	0.39
12 wk	64.6 [61.5–70.5]	62.4 [58.6–66.8]	63.5 [61.0–65.3]	0.28
Swing phase, %				
Preoperative	35.0 [29.0–40.5]	37.2 [35.3–40.5]	35.8 [30.8–39.2]	0.20
6 wk	35.2 [31.4–37.5]	37.1 [34.6–40.5]	34.9 [25.2–39.9]	0.39
12 wk	35.4 [29.5–38.5]	37.6 [33.2–41.4]	36.5 [34.7–39.0]	0.28

*According to one-way analysis of variance.

BMI-matched control group would provide useful information to understanding how well each surgical approach restores gait mechanics. In addition, randomization may have reduced preoperative kinematic and kinetic differences between the cohorts, although these variables are likely more a function of individual differences than sample selection. We did not report changes in leg length and femoral offset following THA, which could affect gait mechanics by changing the length of the muscles around the hip joint. Our findings are limited to a short-term follow-up of 12 weeks, which may be too short a duration in which to observe optimal restoration of gait mechanics in all groups. Finally, our single-centre study design limits the generalizability of the data, as only 3 surgeons performed the procedures.

Despite these limitations, our study has several strengths. It is a prospective study powered to answer a clinically relevant question: Can gait abnormalities following THA be explained by surgical approach? We also compared the 3 most common surgical approaches used for THA, providing useful information for surgeons.[23] Standardization of the implants used at the time of surgery is important. Controlling for this variable helps minimize the influence of implant specifications, such as neck length (femoral offset and leg length) and mode of biologic fixation (proximal versus distal), that may produce biomechanical changes and affect gait postoperatively.[24] The modified Helen Hayes marker set system has been validated for gait analysis, and we took great care to identify the hip joint centre before testing to account for inaccuracy that can occur with varying body habitus. Finally, each approach was performed by a single surgeon, which strengthens the internal validity of the study.

Conclusion

The choice of surgical approach for THA remains a contentious issue. Our study shows that although temporal parameters improve regardless of surgical approach, gait kinematic and kinetic differences still exist. These findings

Table 3. Summary of gait kinematics

Parameter	Group; mean [range], degrees			*p* value*
	Anterior	Posterior	Lateral	
Contralateral pelvic tilt				
Preoperative	2.00 [–5.08 to 10.7]	3.07 [–1.43 to 11.85]	2.60 [–1.10 to 7.78]	0.82
6 wk	1.46 [–0.78 to 5.21]†	3.19 [0.66 to 6.46]	5.03 [1.92 to 10.29]†	0.030
12 wk	2.46 [–0.74 to 5.90]	2.94 [–0.19 to 9.82]	3.56 [–1.48 to 9.39]	0.73
Ipsilateral trunk lean				
Preoperative	1.18 [–0.64 to 5.21]‡	2.82 [–0.80 to 3.53]‡	1.37 [0.12 to 4.72]	0.032
6 wk	0.75 [–0.48 to 2.03]†	1.41 [–0.97 to 4.37]§	3.34 [1.50 to 6.04]†§	0.011
12 wk	0.88 [–1.32 to 3.06]†	1.72 [0.96 to 3.42]	2.42 [1.57 to 3.33]†	0.042
Peak abduction angle				
Preoperative	6.00 [3.74 to 17.81]	3.07 [0.48 to 7.56]	5.14 [0.28 to 12.91]	0.46
6 wk	5.70 [1.24 to 9.65]†	8.55 [4.15 to 12.99]	10.17 [6.88 to 13.10]†	0.033
12 wk	8.38 [3.26 to 14.07]	7.84 [3.32 to 11.14]	10.38 [5.59 to 16.65]	0.34
Peak flexion angle				
Preoperative	10.16 [1.95 to 34.20]	6.19 [2.91 to 22.67]	3.52 [1.90 to 24.77]	0.46
6 wk	5.96 [0.77 to 21.96]	4.50 [1.18 to 12.32]	4.42 [–4.31 to 18.65]	0.94
12 wk	3.45 [0.66 to 15.59]	0.98 [–3.95 to 12.20]	1.12 [–7.84 to 16.13]	0.79
Peak extension angle				
Preoperative	10.87 [3.12 to 34.59]	7.11 [1.95 to 23.50]	4.50 [2.82 to 25.20]	0.48
6 wk	7.21 [0.72 to 23.08]	5.83 [0.54 to 13.04]	5.46 [–4.90 to 19.45]	0.93
12 wk	4.89 [0.89 to 17.31]	2.50 [0.29 to 11.26]	2.48 [–1.23 to 12.90]	0.79
Peak internal rotation angle				
Preoperative	4.94 [0.04 to 19.62]	7.47 [0.43 to 15.58]	7.10 [–2.41 to 17.10]	0.83
6 wk	1.39 [–9.74 to 17.45]	5.24 [–1.44 to 22.42]	10.37 [–5.74 to 19.03]	0.15
12 wk	1.32 [–14.08 to 6.91]†	4.81 [–4.41 to 18.48]	9.10 [–4.00 to 18.95]†	0.012
Peak external rotation angle				
Preoperative	8.11 [0.80 to 15.59]	3.66 [0.26 to 17.88]	1.17 [–17.26 to 11.78]	0.35
6 wk	10.04 [0.19 to 16.61]	5.50 [2.79 to 18.10]	3.85 [0.19 to 19.89]	0.30
12 wk	10.65 [5.35 to 16.22]†	5.08 [–4.86 to 10.99]	0.98 [–2.57 to 9.11]†	0.010

*According to one-way analysis of variance; post hoc testing was completed when $p < 0.05$.
†Post hoc significance between the anterior and lateral group.
‡Post hoc significance between the anterior and posterior group.
§Post hoc significance between the posterior and lateral group.

Table 4. Summary of gait kinetics

Parameter	Group; mean [range], %body weight × height			p value*
	Anterior	Posterior	Lateral	
Peak abduction moment				
Preoperative	4.68 [3.16 to 5.45]	4.17 [2.31 to 5.51]	4.49 [3.12 to 5.80]	0.55
6 wk	5.04 [4.13 to 6.06]	5.30 [4.40 to 6.23]	4.28 [3.56 to 5.47]	0.10
12 wk	5.47 [4.91 to 6.36]	5.41 [4.33 to 7.07]	5.36 [4.39 to 6.21]	0.94
Peak flexion moment				
Preoperative	2.67 [0.53 to 5.63]	2.60 [0.66 to 4.16]	2.25 [0.91 to 3.45]	0.63
6 wk	2.73 [1.56 to 3.74]	2.57 [1.03 to 3.51]	2.20 [1.10 to 3.53]	0.45
12 wk	3.11 [1.36 to 5.77]	3.17 [1.91 to 4.12]	2.80 [1.77 to 4.08]	0.74
Peak extension moment				
Preoperative	–0.46 [–2.21 to 0.75]	–1.36 [–2.88 to 0.05]	–0.99 [–2.48 to –0.11]	0.13
6 wk	–1.00 [–1.89 to –0.59]	–1.62 [–2.51 to –0.71]	–1.08 [–2.38 to 0.05]	0.20
12 wk	–1.25 [–2.70 to –0.61]†	–1.39 [–2.55 to –0.79]	–2.09 [–3.97 to –1.28]†	0.034
Peak internal rotation moment				
Preoperative	–0.38 [–0.82 to 0.004]	–0.40 [–0.38 to –0.15]	–0.64 [–1.25 to –0.19]	0.13
6 wk	–0.63 [–1.40 to –0.18]	–0.61 [–0.96 to –0.23]	–0.73 [–1.14 to –0.39]	0.67
12 wk	–0.72 [–1.36 to –0.18]	–0.65 [–0.97 to –0.42]	–0.87 [–1.38 to –0.63]	0.32
Peak external rotation moment				
Preoperative	0.26 [–0.03 to 0.77]	0.29 [0.03 to 0.39]	0.28 [–0.08 to 0.37]	0.26
6 wk	0.26 [0.01 to 0.49]†	0.37 [0.05 to 0.58]‡	0.11 [–0.11 to 0.16]†‡	0.003
12 wk	0.38 [0.19 to 1.14]†	0.40 [0.02 to 0.76]‡	0.22 [–0.10 to 1.56]†‡	0.011
Peak vertical ground reaction force				
Preoperative	1.02 [0.97 to 1.10]	1.03 [0.97 to 1.13]	1.02 [0.98 to 1.05]	0.55
6 wk	1.05 [0.96 to 1.15]	1.04 [0.97 to 1.14]	1.02 [0.96 to 1.05]	0.47
12 wk	1.05 [0.99 to 1.16]	1.07 [1.01 to 1.20]	1.05 [0.97 to 1.13]	0.81
Peak propulsion at toe-off				
Preoperative	0.10 [0.03 to 0.17]	0.12 [0.08 to 0.19]	0.11 [0.07 to 0.14]	0.39
6 wk	0.13 [0.04 to 0.22]	0.15 [0.12 to 0.21]	0.11 [0.06 to 0.16]	0.41
12 wk	0.14 [0.04 to 0.26]	0.17 [0.14 to 0.22]	0.15 [0.11 to 0.20]	0.54

*According to one-way analysis of variance; post hoc testing was completed when $p < 0.05$.
†Post hoc significance between the anterior and lateral group.
‡Post hoc significance between the posterior and lateral group.

are statistically significant; however, the clinical relevance of these findings is limited to extrapolation based on established literature. The impact of gait anomalies on the long-term mechanical durability of implant fixation remains unknown. Future studies, such as corroborating biomechanical changes with soft tissue changes seen on cross-sectional imaging with long-term follow-up, would provide insight into how healed or unhealed tissue may explain gait aberrancies.

Affiliations: From the Division of Orthopedic Surgery, London Health Sciences Centre, London, Ont. (Petis, Howard, Lanting, Vasarhelyi); and the Wolf Orthopaedic Biomechanics Laboratory, Western University, London, Ont. (Birmingham, Jones).

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