JB&JS REVIEWS

Postoperative Gait Mechanics After Total Hip Arthroplasty

A Systematic Review and Meta-Analysis

Rebecca Moyer, PT, PhD

Brent Lanting, MD

Jacquelyn Marsh, PhD

Abdulaziz Al-Jurayyan, MD, MSc

Laura Churchill, MSc

James Howard, MD

Lyndsay Somerville, PhD

Investigation performed at the University of Western Ontario, London, Ontario, and Dalhousie University, Halifax, Nova Scotia, Canada

Abstract

Background: Total hip arthroplasty is recommended by clinical practice guidelines for improving pain in patients with severe hip osteoarthritis, yet functional limitations may persist postoperatively. The effects of the surgical approach on postoperative gait biomechanics may influence these limitations after total hip arthroplasty but are currently not well established. The purpose of this study was to investigate the differences in postoperative gait biomechanical differences, at early and late follow-up, in patients with hip osteoarthritis who underwent total hip arthroplasty using different surgical approaches.

Methods: Four electronic databases were searched from their inception to December 2016. Four pairs of reviewers independently determined study eligibility, rated study quality, and extracted data. Pooled estimates for each meta-analysis were obtained using a random-effects model. Mean differences (MDs) and standardized mean differences (SMDs) were calculated for spatiotemporal, kinematic, and kinetic gait variables at early (≤3 months) and late (≥6 months) postoperative follow-up. The posterior, anterior, direct lateral, and anterolateral approaches were compared using the mean postoperative differences between approaches, standard deviations, and sample sizes.

Results: Nineteen studies (757 participants) were included. Individual and pooled effect sizes for the differences between approaches were inconsistent, with minimal significant differences at early or late follow-up. A significant increase in step length was observed after the posterior approach compared with the anterolateral approach at early (SMD = 0.68, p = 0.035) and late (SMD = 0.46, p = 0.032) follow-up, as well as a significant increase in hip adduction moment after the posterior approach compared with the lateral approach at early follow-up (SMD = 0.70, p = 0.020). Effect sizes ranged from small to very large, but too few studies comparing similar surgical approaches, as well as inconsistent reporting of outcome measures, limited the ability to pool data.

Conclusions: These findings suggest little early or late postoperative difference in gait biomechanics between surgical approaches. Although some significant differences between surgical approaches exist, determining whether the reported postoperative gait value differences are clinically meaningful remains a substantial challenge for the interpretation of these findings.

Level of Evidence: Therapeutic Level II. See Instructions for Authors for a complete description of levels of evidence.

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Total hip arthroplasty (THA) is recommended by clinical practice guidelines as a reliable procedure for improving pain in patients with severe hip osteoarthritis[1-3], with approximately 80% of patients satisfied after surgery[4,5]. However, limited restoration of physical function may persist after THA[6,7]. Between 14% and 22% of patients report limitations in walking after surgery[8,9] and may therefore be less likely to achieve clinically meaningful improvements in function[6,10]. Previous systematic reviews have highlighted the surgical effects on clinical outcomes such as pain and function following THA[11-13], but there has been little synthesis of the effects on postoperative gait biomechanics. Although walking generally improves after surgery, these functional gains do not necessarily reach magnitudes equivalent to those in healthy control populations[8,14-16], or correlate well with patient-reported measures of function[17].

There is growing interest surrounding the various surgical approaches for THA and their impact on gait biomechanics. Commonly used surgical approaches for THA, including the direct posterior, direct anterior (or Hueter), direct lateral (or Hardinge), and anterolateral (or Watson-Jones) approaches, differ in the direction of the approach and alter different anatomical structures[18]. The direct posterior approach detaches the small external hip rotators and disrupts the posterior joint capsule, while avoiding the hip abductors, increasing the risk of postoperative dislocation[18,19]. Conversely, the direct lateral approach detaches the hip abductor muscles, increasing the risk of postoperative abductor weakness[18-20]. In contrast, the direct anterior and anterolateral approaches are less invasive, using muscle-sparing techniques to minimize these associated risks[18]. Whether the surgical impact on different anatomical structures results in a substantial difference with respect to mobility after surgery is unclear, but the approach may have important implications for an individual's return to work, activities of daily living, or recreational activities.

Quantitative gait analysis may help in understanding the gait mechanics that are potentially responsible for the functional limitations observed in patients after surgery. Several recent systematic reviews investigated potential differences in over-ground walking after surgery; however, the comparisons were made between patients after THA and healthy controls[21-23]. Observations included decreases in gait speed, stride length, sagittal hip range of motion, and hip abduction moment, but increases in hip flexion and extension moments, after THA; however, the clinical importance of these findings was unclear. Despite advances in surgical techniques, these reviews combined all THA approaches into a single comparison group; therefore, the importance of surgical approach for the outcomes after THA remains unknown, and the impact that surgical approach could have on these comparisons with healthy control populations has not been established. Thus, the purpose of the present systematic review and meta-analysis was to investigate the differences in postoperative gait biomechanics, at early and late follow-up, between patients with hip osteoarthritis who had undergone different THA surgical approaches.

Materials and Methods

Literature Sources and Study Selection

We systematically searched the MEDLINE, AMED, OVID Healthstar, and Embase electronic databases from their inception to December 2016. Searches used key terms including (hip OR joint) AND (arthroplasty OR replacement) AND (posterior OR anterior OR lateral). We also searched using several specific names for approaches, including Smith-Petersen, Watson-Jones, Hueter, minimally invasive, Hardinge, and Kocher-Langenbeck. We manually searched the reference lists of potentially eligible articles for additional articles to be included. The search strategy can be obtained from the authors. Randomized controlled trials (RCTs) and non-randomized biomechanical studies, published as full-text English-language journal articles, comparing the postoperative gait biomechanical outcomes between 2 or more surgical approaches for primary THA were included. There were no restrictions on study dates, the development or severity of osteoarthritis, or follow-up duration. A protocol for this review has not been previously published.

Determining Inclusion

We included eligible studies that (1) evaluated patients undergoing primary THA for osteoarthritis; (2) compared 2 or more surgical techniques including the posterior, anterior, direct lateral (or Hardinge), and anterolateral (or Watson-Jones) approaches; (3) included at least 1 biomechanical outcome of interest; and (4) were published in English. Studies including patients undergoing bipolar hemiarthroplasty or hip resurfacing, studies involving arthroplasty for femoral fractures, and studies that evaluated a 2-incision technique versus a different approach were excluded. Four pairs of reviewers blinded to journal title and authorship independently assessed eligibility in 2 stages. We first reviewed all titles and abstracts of the results found using the initial search strategy. Articles meeting the eligibility criteria were obtained as full-text manuscripts. If an eligible title and abstract were categorized as "uncertain," or the reviewers disagreed about their eligibility for inclusion, the article was obtained as a full-text manuscript and was independently reviewed by each reviewer pair using the same eligibility criteria. Discrepancies were discussed until a consensus was achieved. Details of the literature search are reported using the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines[24].

Quality Assessment

Four pairs of reviewers rated study quality. We used the Cochrane Collaboration's Risk of Bias tool for assessing the risk of bias for RCTs[25] and the ACROBAT-NRSI (A Cochrane Risk Of Bias Assessment Tool: for Non-Randomized Studies of Interventions) for assessing nonrandomized biomechanical studies[26]. The Cochrane Risk of Bias tool consists of 6 domains or subdomains: selection bias (sequence generation and treatment allocation), performance bias, detection bias, attrition bias (incomplete outcome data), and reporting bias. Each item was rated as low, uncertain, or high risk. The ACROBAT-NRSI consists of 8 domains: confounding bias, selection bias, intervention classification bias, intervention deviations, missing data, measurement bias, reporting bias, and a category for other sources of bias. For the current review, other sources of bias included no preoperative data, variability in surgeon experience, and procedures conducted within the surgeon's learning curve. We did not use findings from the quality assessments to exclude eligible articles; however, we did use the overall quality of the evidence to assist in making recommendations based on the meta-analysis findings and to explain potential heterogeneity among studies (when possible).

Outcome Measures and Data Extraction

We categorized outcome measures into 3 groups: (1) spatiotemporal parameters, (2) gait kinematics, and (3) gait kinetics. For gait kinematics, the range of motion in each anatomical plane was included as a measure of the full joint excursion throughout the gait cycle. Peak flexion, extension, adduction, and internal and external rotation angles were obtained during the stance phase, while the peak abduction angle was obtained during the swing phase. All gait kinetic measures were obtained as the peak value recorded during stance. We independently extracted data from eligible articles in 4 reviewer pairs. Data regarding individual group results were extracted at each postoperative follow-up time, using either means and standard deviations (SDs) or mean differences (MDs), for each continuous outcome measure of interest, and were categorized as representing either early (i.e., ≤3 months after surgery) or late (i.e., ≥6 months after surgery) postoperative follow-up. The reviewers also extracted the following information from each article: author and year, study design, sample size, patient demographics, surgical technique, follow-up duration, and participant retention. We contacted authors when study information or data were not reported or were unclear.

Statistical Analysis

We calculated interobserver agreement regarding study eligibility using the kappa statistic, which was classified as follows: no agreement (≤0), poor agreement (0.01 to 0.20), slight agreement (0.21 to 0.40), fair agreement (0.41 to 0.60), good agreement (0.61 to 0.80), very good agreement (0.81 to 0.92), and excellent agreement (0.93 to 1.00)[27]. We identified the posterior approach, which has a longstanding history in orthopaedics[28], as the "gold standard" surgical technique (i.e., the control). When the posterior approach was not evaluated, we then considered the anterior approach as the alternative technique of interest (control), as it is the most rapidly growing approach and is considered a "competitor" to the posterior approach[29]. When neither the posterior nor the anterior approach were evaluated, the direct lateral approach was considered the third technique of

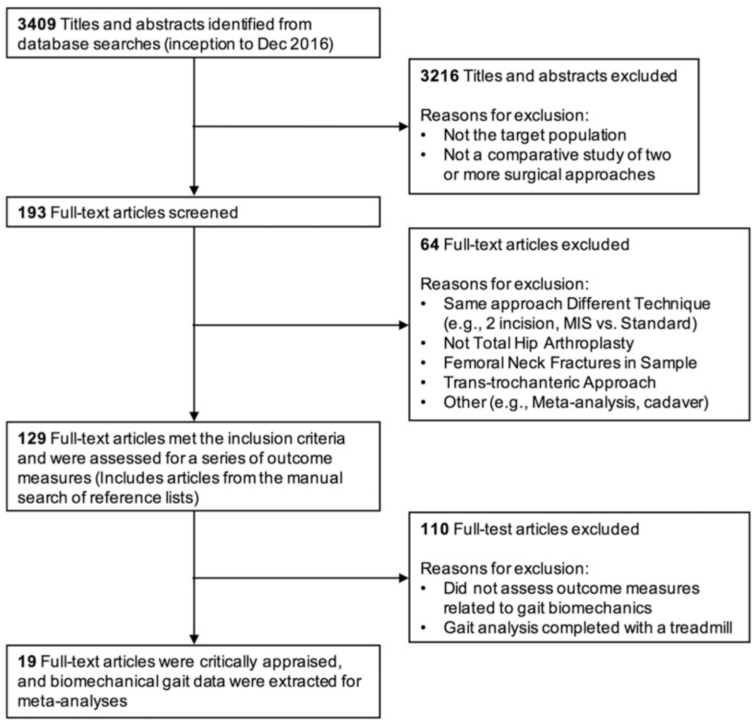

Fig. 1

Flowchart showing identification of the included studies, presented in accordance with the PRISMA 2009 guidelines for systematic reviews and meta-analyses[24]. Nineteen studies were included in the descriptive and qualitative analysis. MIS = minimally invasive surgery.

TABLE I Characteristics of Included Studies (N = 19)*

Study	Surgical Technique	N	Age† *(yr)*	Female *(%)*	BMI† *(kg/m²)*	Time *(wk)*
Madsen (2004)[34]	Posterior/direct lateral/ healthy control	10/10/9	6±8/61±8/54±10	50/60/44.4	27.5/24.9/23.8	24
Meneghini (2008)[35]	Posterior/direct lateral/2-incision MIS	8/8/8	54 (38-74)	NR	26 (21-30)	6
Whatling (2008)[36]	Posterior/direct lateral/ healthy control	13/14/16	61±12/64±11/46±7	NR	30.6/31.2/25.3	6‡
Maffiuletti (2009)[37]	Posterior/anterior/healthy control	17/17/17	69±5/68±6/69±4	41.2/41.2/41.2	27.2±4.2/25.6±3.3/25.5±2.7	24
Mayr (2009)[38]	Anterior/direct lateral	16/17	65 (55-84)/69 (59-78)	64.7/52.9	27 (20.8-36.1)/29 (20.2-34.7)	6, 12
Klausmeier (2010)[39] and Lugade (2010)[40]	Anterior/direct lateral/ healthy control	12/11/10	57±3/57±7/60±5	33/18/50	32.0±5.1/31.1±4.1/26.3±3.9	6, 16
Pospischill (2010)[41]	Direct lateral/anterolateral	20/20	61/62	40/60	25.7/25.7	12
Martin (2011)[42]	Direct lateral/anterolateral	41/42	63±10/67±10	66/71	29.4±5.5/30.6±6.1	52
Queen (2011)[43]	Posterior/direct lateral/ anterolateral	8/8/15	55±8/58±7/55±11	50/50/53.3	25.2/27.7/30.0	6
Müller (2012)[44]	Direct lateral/anterolateral	15/15	66±8/64±7	66.7/60	27.0±3.1/26.9±3.3	12
Reininga (2013)[45]	Posterior/anterior	40/35	61±10/60±8	80/69	26.2±3.5/27.3±3.5	6, 12, 24
Queen (2013)[46]	Posterior/direct lateral/ anterolateral	10/10/10	57±6/60±6/58±11	NR	26.3/26.6/28.8	6, 52
Varin (2013)[47]	Anterior/direct lateral/ healthy control	20/20/20	61±6/66±7/64±4	70/50/50	28.5±2.8/27.2±5.0/24.9±3.5	38
Rathod (2014)[48]	Posterior/anterior	11/11	62±9/58±7	54.5/45.5	25.4±3.1/25.9±2.2	24, 52
Queen (2014)[49]	Posterior/direct lateral/ anterolateral	18/1/11	NR	NR	NR	52
Nishimura (2016)[50]	Direct lateral/anterolateral	8/7	68±7/63±13	87.5/85.7	24.1±2.1/23.9±2.3	9, 28
Rosenlund (2016)[51]	Posterior/direct lateral	23/24	61±7/61±7	26/29	27.5±3.8/27.3±3.4	12, 52
Martz (2016)[52]	Posterior/anterolateral	32/38	68±10/67±9	43.8/63.2	28.8±4.3/27.3±5	24

*BMI = body mass index, NR = not reported, MIS = minimally invasive surgery, OA = osteoarthritis, RA = rheumatoid arthritis, and ON = osteonecrosis. †The values are presented as the mean with or without the standard deviations and with or without the range in parentheses. ‡Whatling et al. did not report the postoperative time at which gait was assessed. Authors were contacted, with no response. Six weeks is an estimated time point based on the values recorded by other studies at a similar follow-up.

interest or control. MDs and standardized MDs (SMDs) were calculated using the earliest or last postoperative follow-up. The SMD was calculated as the postoperative difference between the control and experimental groups (MD) divided by the pooled SD. When possible, pooled estimates and 95% confidence intervals (CIs) for the MD and SMD were calculated using the inverse-variance method and random-effects model (Comprehensive Meta-Analysis software, version 2; BioStat). Outcomes favoring the control group were represented as a positive value, and the magnitude of the SMD was interpreted using the Cohen d statistic[30]. Results were considered to be significant if $p < 0.05$ or if the 95% CI did not cross zero. The proportion of variability associated with heterogeneity was assessed using the I^2 and Q statistics[31-33]. An I^2 value of 25% was interpreted as low heterogeneity; 50%, moderate heterogeneity; and 75%, high heterogeneity[33].

Results

Study Selection and Characteristics

We identified 2,497 potentially relevant articles from the literature search. We screened 109 full-text articles, and 19 studies with 757 participants met the eligibility criteria and were included in the final analyses (Fig. 1)[34-52]. Interrater agreement was good to excellent for determining eligibility for titles and abstracts (kappa = 0.74) and full-text articles (kappa = 0.95). A total of 677 participants underwent THA using 1 of the 4 surgical approaches of interest: posterior (n = 190, 28%), anterior (n = 111, 16%), direct lateral (n = 218, 33%), or anterolateral (n = 158, 23%). The presented analyses exclude data from 72 healthy controls[34,36,39,40,47]

TABLE I (continued)

Dropout (%)	Diagnosis	Limb	Implant Technology: Design	Implant Technology: Manufacturer
0/0/0	NR	Unilateral	Cemented Stanmore, all-polyethylene socket	NR
0/12.5/0	OA, RA, secondary arthritis, or dysplasia	Unilateral	Trilogy cementless press-fit	Zimmer
53.3/64.3/0	NR	NR	NR	NR
0/0/0	OA	Unilateral	NR	NR
0/0	Hip disease	Unilateral	Trident cup and Accolade TMZF stem	Stryker
0/0/0	OA	Unilateral	Trilogy cementless press-fit cup and Alloclassic stem or fiber metal taper (uncemented)	Zimmer
5/5	OA	Unilateral	Cementless Alloclassic Variall system	Zimmer
4.9/4.7	OA, ON, coxa vara, or dysplasia	NR	Cemented stem and cemented, or press-fit, acetabular components	Zimmer and Orthogese
0/0/0	NR	Unilateral	NR	NR
0/0	Coxarthrosis or OA	Unilateral	Uncemented Allofit press-fit cup and uncemented Alloclassic stem	Zimmer
0/0	Primary or secondary OA	Unilateral	Trident cup and ABG II femoral component	Stryker
0/0/0	NR	Unilateral	NR	NR
0/0/0	OA	NR	Trident cup and Accolade stem or Lineage, Conserve, or Dynasty cup and Profemur stem	Stryker and Wright Medical Tech.
0/27.3	Primary OA	Unilateral	Uncemented Trident cup and Accolade stem	Stryker
0/0/0	NR	Unilateral	NR	NR
0/0	OA	Unilateral	Uncemented cup and irradiated polyethylene liner	NR
4.3/0	Primary OA	Unilateral	Uncemented Bimetric stem, Exceed ABT Ringloc-x shell	NR
0/0	OA	Unilateral	Uncemented dual-mobility cup (Tregor; Sunfit) and femoral stem (Semetric; XO)	Ashton Medical, SERF, SEM

and 8 participants who underwent an alternative surgical technique[35]. Individual study characteristics are presented in Table I.

Methodological Quality Assessment

Results for the methodological quality assessments are reported in Tables II and III. All RCTs had low risk of bias in most categories except for selection bias, which had unclear risk, and 1 trial that had high risk of reporting bias. For cross-sectional and prospective cohorts, risk of bias was unclear to moderate for most categories and moderate or higher for reporting bias. Other risks of bias included no preoperative data, experience variability among surgeons, and 1 procedure conducted within the surgeon's learning curve. Because of the small number of eligible studies, no studies were excluded from the analyses on the basis of quality.

Posterior Versus Anterior Approach

Two observational cohorts and 1 RCT compared the effects of the posterior and anterior approaches. Individual and pooled effect sizes are presented in Table IV. No studies could be pooled to evaluate early postoperative effects on gait; however, overall pooled analyses at late follow-up suggested little to no difference between approaches with respect to the duration in stance (SMD = 0.11) or gait speed (SMD = −0.22). Reininga et al.[45] and Rathod et al.[48] suggested that patients treated with the anterior approach had significantly less pelvic obliquity[45] at 6 months of follow-up ($p = 0.012$) and larger sagittal plane range of motion ($p < 0.001$) and hip flexion moments ($p = 0.009$), extension moments ($p = 0.017$), and external rotation moments ($p = 0.002$) at 1 year of follow-up[48]. No other significant differences were observed between the approaches, and effect sizes varied.

Posterior Versus Lateral Approach

Four observational cohorts and 2 RCTs compared the effects of the posterior and lateral approaches. Individual and pooled effect sizes are presented in Table V. Overall, there was a moderate to large, significant pooled effect size, in favor of the posterior approach (SMD = 0.70,

TABLE II Methodological and Quality Assessment of the Randomized Controlled Trials (N = 7)

Study	Selection Bias: Random Sequence Generation	Selection Bias: Concealed Treatment Allocation	Performance Bias: Blinded Participants and Personnel*	Detection Bias: Blinded Outcome Assessment*	Attrition Bias: Incomplete Outcome Data	Reporting Bias
Meneghini[35]	Low risk	Unclear	Low risk	Low risk	Low risk	Low risk
Mayr[38]	Low risk	Unclear	Low risk	Low risk	Low risk	High risk
Pospischill[41]	Low risk	Unclear	Low risk	Low risk	Low risk	Low risk
Martin[42]	Unclear	Unclear	Low risk	Low risk	Low risk	Low risk
Müller[44]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Reininga[45]	Low risk	Low risk	Low risk	Low risk	Unclear	Low risk
Rosenlund[51]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

*All were categorized as low because of the objective nature of gait analysis.

p = 0.020), suggesting that these patients had a larger hip adduction moment at 6 weeks after surgery. However, this finding was not supported by a randomized trial[35] with early follow-up or by other observational studies investigating this effect at 1 year[46,49]. Whatling et al.[36] and Queen et al.[43] suggested that patients treated with the posterior approach had a significantly larger abduction angle (p = 0.035) and smaller adduction angle (p = 0.045), but greater pelvic obliquity (p = 0.029), at 6 weeks. At 1 year, Rosenlund et al.[51] suggested that these patients also walked with a longer single-limb support phase (p = 0.039). No other significant differences were observed between the approaches; however, although the effect sizes varied, the nonsignificant findings commonly favored the posterior approach.

Posterior Versus Anterolateral Approach

Four observational cohort studies and no RCTs compared the effects of the posterior and anterior approaches. Individual and pooled effect sizes are presented in Table VI. At early and late follow-up, there was an overall moderate to large, significant pooled effect size, in favor of the posterior approach (SMD = 0.68, p = 0.035; SMD = 0.46, p = 0.032), suggesting that these patients had a longer step length. However, Martz et al.[52] suggested that sagittal plane range of motion was significantly less in patients treated with the posterior approach at 6 months (p < 0.001). Queen et al.[43] and Martz et al.[52] also suggested that these patients had a significantly smaller adduction angle at 6 weeks (p = 0.047) but had larger frontal plane range of motion at 6 months (p = 0.043) compared with the anterolateral approach. No other

TABLE III Methodological and Quality Assessment of the Observational Cohort Studies with or without Concurrent Healthy Controls (N = 12)

Study	Confounding	Study Participant Selection	Classification of Interventions	Deviation from Interventions	Missing Data	Outcome Measurement*	Reporting Bias	Other†
Madsen[34]	Unclear	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	1
Whatling[36]	Unclear	Unclear	Low risk	Unclear	Low risk	Low risk	Critical risk	1
Maffiuletti[37]	Low risk	Low risk	Low risk	Moderate risk	Unclear	Low risk	Moderate risk	1, 2
Klausmeier[39] ‡	Moderate risk	Low risk	Low risk	Low risk	Unclear	Low risk	Serious	2, 3
Lugade[40]	Low risk	Low risk	Low risk	Low risk	Unclear	Low risk	Low risk	2, 3
Queen (2011)[43]	Unclear	Low risk	Low risk	Unclear	Unclear	Low risk	Moderate risk	—
Queen (2013)[46]	Unclear	Low risk	Low risk	Low risk	Unclear	Low risk	Moderate risk	—
Varin[47] ‡	Moderate risk	Moderate risk	Moderate risk	Unclear	Moderate risk	Moderate risk	Moderate risk	—
Rathod[48]	Low risk	Low risk	Low risk	Serious risk	Serious risk	Low risk	Moderate risk	2
Queen (2014)[49]	Unclear	Low risk	Low risk	Low risk	Unclear	Low risk	Moderate risk	—
Nishimura[50]	Unclear	Moderate risk	Low risk	Low risk	Unclear	Low risk	Low risk	—
Martz[52]	Unclear	Moderate risk	Low risk	Low risk	Low risk	Low risk	Low risk	2

*All were categorized as low because of the objective nature of gait analysis. †Other risks of bias include (1) no preoperative data, (2) surgeon experience variable, and (3) 1 procedure conducted within the surgeon's learning curve. ‡Klausmeier et al. and Varin et al. recruited (the same) patients retrospectively. All other studies had a cross-sectional or prospective cohort design.

TABLE IV Comparisons Between the Posterior (Control) and Anterior (Experimental) Approaches*

Characteristic and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value	Heterogeneity		
								I^2	Q	P Value
Spatiotemporal gait characteristics										
Duration in stance										
Maffiuletti[37]	Obs.	Late	24	−0.02	−0.35	−1.03, 0.33	0.312			
Rathod[48]	Obs.	Late	52	0.11	0.64	−0.21, 1.50	0.141			
Random-effects model		Late		0.03	0.11	−0.86, 1.08	0.823	68.5%	3.171	0.075
Single-limb support										
Maffiuletti[37]	Obs.	Late	24	0.30	0.26	−0.42, 0.93	0.453			
Double-limb support										
Maffiuletti[37]	Obs.	Late	24	−0.80	−0.32	−0.99, 0.36	0.352			
Gait speed										
Reininga[45]	RCT	Early	6	0.00	0.00	−0.45, 0.45	1.000			
Maffiuletti[37]	Obs.	Late	24	0.03	0.20	−0.48, 0.87	0.566			
Rathod[48]	Obs.	Late	52	−0.11	−0.72	−1.58, 0.14	0.102			
Random-effects model		Late		−0.04	−0.22	−1.11, 0.68	0.630	62.8%	2.693	0.101
Reininga[45]	RCT	Late	24	0.00	0.00	−0.45, 0.45	1.000			
Stride length										
Maffiuletti[37]	Obs.	Late	24	0.01	0.07	−0.60, 0.74	0.840			
Step length										
Reininga[45]	RCT	Early	6	−0.03	−0.25	−0.71, 0.21	0.281			
Reininga[45]	RCT	Late	24	−0.02	−0.26	−0.71, 0.20	0.268			
Kinematic gait characteristics										
Sagittal plane range of motion										
Rathod[48]	Obs.	Late	52	−10.00	−1.64	−2.61, −0.68	<0.001			
Frontal plane range of motion										
Rathod[48]	Obs.	Late	52	2.00	0.59	−0.28, 1.45	0.183			
Transverse plane range of motion										
Rathod[48]	Obs.	Late	52	−4.91	−0.76	−1.62, 0.11	0.087			
Pelvic obliquity										
Reininga[45]	RCT	Early	6	0.40	0.27	−0.19, 0.72	0.255			
Reininga[45]	RCT	Late	24	0.80	0.59	0.13, 1.06	0.012			
Kinetic gait characteristics										
Hip flexion moment										
Rathod[48]	Obs.	Late	52	−0.29	−1.22	−2.13, −0.31	0.009			
Hip extension moment										
Rathod[48]	Obs.	Late	52	−0.34	−1.09	−1.99, −0.20	0.017			
Hip adduction moment										
Rathod[48]	Obs.	Late	52	0.05	0.25	−0.59, 1.09	0.561			
Hip internal rotation moment										
Rathod[48]	Obs.	Late	52	0.00	0.00	−0.84, 0.84	1.000			
Hip external rotation moment										
Rathod[48]	Obs.	Late	52	−0.15	−1.53	−2.48, −0.58	0.002			

*MD = mean difference, SMD = standardized mean difference, Obs. = observational cohort study, and RCT = randomized controlled trial. †Positive values indicate that the posterior approach (control) had larger values.

significant differences were observed between the approaches, and effect sizes varied.

Anterior Versus Lateral Approach

Three observational cohort studies and no RCTs compared the effects of the anterior and lateral approaches. Individual effect sizes are presented in Table VII. No studies could be pooled to

TABLE V Comparisons Between the Posterior (Control) and Lateral (Experimental) Approaches*

Characteristic and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value	Heterogeneity I^2	Heterogeneity Q	Heterogeneity P Value
Spatiotemporal gait characteristics										
Duration in stance										
Whatling[36]	Obs.	Early	6	−0.02	−0.26	−1.51, 0.98	0.679			
Queen (2011)[43]	Obs.	Early	6	2.05	0.35	−0.64, 1.34	0.484			
Random-effects model		Early		−0.02	0.12	−0.66, 0.89	0.771	0.0%	0.575	0.448
Meneghini[35]	RCT	Early	6	0.18	0.73	−0.28, 1.75	0.156			
Single-limb support										
Whatling[36]	Obs.	Early	6	1.40	0.23	−1.02, 1.47	0.719			
Rosenlund[51]	RCT	Late	52	1.20	0.62	0.03, 1.20	0.039			
Double-limb support										
Whatling[36]	Obs.	Early	6	−1.02	−0.18	−1.43, 1.06	0.773			
Gait speed										
Whatling[36]	Obs.	Early	6	0.05	0.23	−1.02, 1.47	0.718			
Queen (2011)[43]	Obs.	Early	6	0.18	0.82	−0.20, 1.84	0.115			
Queen (2013)[46]	Obs.	Early	6	0.08	0.49	−0.41, 1.37	0.285			
Random-effects model		Early		0.10	0.54	−0.05, 1.14	0.073	0.0%	0.543	0.762
Meneghini[35]	RCT	Early	6	−0.08	−0.36	−1.34, 0.67	0.496			
Madsen[34]	Obs.	Late	24	0.00	0.00	−0.88, 0.88	1.000			
Queen (2013)[46]	Obs.	Late	52	−0.03	−0.12	−1.00, 0.76	0.784			
Random-effects model		Late		−0.01	−0.06	−0.68, 0.56	0.847	0.0%	0.037	0.847
Rosenlund[51]	RCT	Late	52	−0.08	−0.45	−1.03, 0.39	0.135			
Stride length										
Whatling[36]	Obs.	Early	6	0.05	0.29	−0.96, 1.54	0.649			
Queen (2011)[43]	Obs.	Early	6	0.02	0.23	−0.75, 1.21	0.645			
Queen (2013)[46]	Obs.	Early	6	0.03	0.20	−0.68, 1.08	0.656			
Random-effects model		Early		0.03	0.23	−0.35, 0.81	0.437	0.0%	0.013	0.993
Madsen[34]	Obs.	Late	24	−0.02	−0.12	−0.99, 0.76	0.794			
Queen (2013)[46]	Obs.	Late	52	0.03	0.17	−0.71, 1.05	0.710			
Random-effects model		Late		0.01	0.03	−0.60, 0.65	0.938	0.0%	0.200	0.654
Rosenlund[51]	RCT	Late	52	−0.05	−0.32	−0.90, 0.25	0.272			
Step length										
Queen (2011)[43]	Obs.	Early	6	−0.01	−0.11	−1.09, 0.87	0.824			
Queen (2013)[46]	Obs.	Early	6	0.03	0.32	−0.57, 1.20	0.483			
Random-effects model		Early		0.01	0.13	−0.53, 0.78	0.709	0.0%	0.402	0.526
Queen (2013)[46]	Obs.	Late	52	0.03	0.33	−0.55, 1.21	0.462			
Kinematic gait characteristics										
Sagittal plane range of motion										
Whatling[36]	Obs.	Early	6	2.85	0.44	−0.81, 1.70	0.490			
Madsen[34]	Obs.	Late	24	5.40	0.84	−0.08, 1.75	0.072			
Rosenlund[51]	RCT	Late	52	−1.80	−0.25	−0.82, 0.33	0.397			
Peak flexion angle										
Queen (2011)[43]	Obs.	Early	6	1.21	0.15	−0.83, 1.13	0.763			
Peak extension angle										
Queen (2011)[43]	Obs.	Early	6	0.37	0.04	−0.94, 1.02	0.930			
Frontal plane range of motion										
Whatling[36]	Obs.	Early	6	−0.11	−0.04	−1.28, 1.20	0.948			
Rosenlund[51]	RCT	Late	52	−1.50	−0.58	−1.16, 0.01	0.051			

continued

TABLE V (*continued*)

Characteristic and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value	Heterogeneity		
								I^2	Q	P Value
Peak adduction angle										
Queen (2011)[43]	Obs.	Early	6	−3.20	−0.93	−1.98, 0.12	0.045			
Peak abduction angle										
Queen (2011)[43]	Obs.	Early	6	3.20	1.04	0.08, 2.01	0.035			
Madsen[34]	Obs.	Late	24	1.90	0.48	−0.41, 1.36	0.295			
Transverse plane range of motion										
Whatling[36]	Obs.	Early	6	2.12	0.65	−0.63, 1.92	0.319			
Rosenlund[51]	RCT	Late	52	−0.60	−0.04	−0.54, 0.41	0.642			
Pelvic tilt										
Whatling[36]	Obs.	Early	6	−1.39	−0.83	−2.12, 0.46	0.208			
Pelvic obliquity										
Whatling[36]	Obs.	Early	6	2.21	1.59	0.17, 3.0	0.029			
Madsen[34]	Obs.	Late	24	1.70	0.79	−0.13, 1.79	0.096			
Rosenlund[51]	RCT	Late	52	−0.40	−0.21	−0.78, 0.36	0.472			
Pelvic rotation										
Whatling[36]	Obs.	Early	6	2.66	0.42	−0.83, 1.68	0.508			
Kinetic gait characteristics										
Hip extension moment										
Queen (2013)[46]	Obs.	Early	6	0.15	0.54	−0.35, 1.44	0.233			
Queen (2013)[46]	Obs.	Late	52	0.05	0.15	−0.73, 1.03	0.741			
Hip adduction moment										
Whatling[36]	Obs.	Early	6	0.19	0.86	0.04, 1.62	0.033			
Queen (2013)[46]	Obs.	Early	6	0.13	0.50	−0.39, 1.39	0.271			
Random-effects model		Early		0.17	0.70	0.11, 1.29	0.020	0.0%	0.347	0.556
Meneghini[35]	RCT	Early	6	0.06	0.28	−0.70, 1.27	0.571			
Queen (2013)[46]	Obs.	Late	52	0.03	0.16	−0.72, 1.04	0.720			
Queen (2014)[49]	Obs.	Late	52	−0.06	−0.39	−1.12, 0.35	0.305			
Random-effects model		Late		−0.03	−0.16	−0.72, 0.40	0.579	0.0%	0.873	0.350
Ground reaction force										
Whatling[36]	Obs.	Early	6	0.04	0.51	−0.75, 1.77	0.431			
Queen (2011)[43]	Obs.	Early	6	0.05	0.51	−0.49, 1.50	0.320			
Queen (2013)[46]	Obs.	Early	6	0.06	0.21	−0.67, 1.09	0.635			
Random-effects model		Early		0.05	0.38	−0.21, 0.96	0.206	0.0%	0.237	0.888
Meneghini[35]	RCT	Early	6	0.01	0.14	−0.84, 1.12	0.775			
Queen (2013)[46]	Obs.	Late	52	−0.01	−0.14	−1.02, 0.74	0.759			

*MD = mean difference, SMD = standardized mean difference, Obs. = observational cohort study, and RCT = randomized controlled trial.
†Positive values indicate that the posterior approach (control) had larger values.

evaluate early or late postoperative effects on gait. Klausmeier et al.[39] suggested that patients treated with the anterior approach had a significantly larger external rotation moment at 6 weeks ($p = 0.019$), and Varin et al.[47] suggested that at 9 months these patients also had a significantly smaller hip adduction moment ($p = 0.002$), walked faster ($p = 0.005$), and had more pelvic tilt ($p = 0.036$). Several moderate to large effect sizes in favor of the anterior approach were noted for the remaining outcomes, yet no other significant differences were observed between approaches.

Anterior Versus Anterolateral Approach

One RCT compared the effects of the anterior and anterolateral approaches; therefore, no pooling of studies could be performed. Individual effect sizes are presented in Table VIII. Mayr et al.[38] suggested that the peak hip abduction angle

TABLE VI Comparisons Between the Posterior (Control) and Anterolateral (Experimental) Approaches

Characteristic and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value	Heterogeneity I^2	Heterogeneity Q	Heterogeneity P Value
Spatiotemporal gait characteristics										
Duration in stance										
Queen (2011)[43]	Obs.	Early	6	−0.21	−0.05	−0.91, 0.80	0.901			
Single-limb support										
Martz[52]	Obs.	Late	24	1.00	0.39	−0.09, 0.86	0.111			
Double-limb support										
Martz[52]	Obs.	Late	24	−1.00	−0.20	−0.67, 0.27	0.406			
Gait speed										
Queen (2011)[43]	Obs.	Early	6	0.08	0.42	−0.35, 1.18	0.292			
Queen (2013)[46]	Obs.	Early	6	−0.04	−0.21	−1.09, 0.67	0.641			
Random-effects model		Early		0.02	0.11	−0.51, 0.73	0.728	0.0%	0.998	0.318
Queen (2013)[46]	Obs.	Late	52	−0.03	−0.12	−1.00, 0.76	0.784			
Martz[52]	Obs.	Late	24	0.06	0.26	−0.22, 0.73	0.285			
Random-effects model		Late		0.04	0.17	−0.25, 0.59	0.417	0.0%	0.559	0.455
Stride length										
Queen (2011)[43]	Obs.	Early	6	0.04	0.57	−0.30, 1.44	0.201			
Queen (2013)[46]	Obs.	Early	6	0.00	0.00	−0.88, 0.88	1.000			
Random-effects model		Early		0.03	0.29	−0.33, 0.91	0.365	0.0%	0.815	0.367
Queen (2013)[46]	Obs.	Late	52	0.03	0.17	−0.71, 1.05	0.710			
Step length										
Queen (2011)[43]	Obs.	Early	6	0.04	0.65	−0.23, 1.53	0.146			
Queen (2013)[46]	Obs.	Early	6	0.05	0.71	−0.20, 1.61	0.126			
Random-effects model		Early		0.04	0.68	0.05, 1.31	0.035	0.0%	0.007	0.934
Queen (2013)[46]	Obs.	Late	52	0.03	0.33	−0.55, 1.21	0.462			
Martz[52]	Obs.	Late	24	0.03	0.50	0.02, 0.97	0.042			
Random-effects model		Late		0.03	0.46	0.04, 0.88	0.032	0.0%	0.104	0.747
Kinematic gait characteristics										
Sagittal plane range of motion										
Martz[52]	Obs.	Late	24	−8.00	−1.26	−1.78, −0.75	<0.001			
Peak flexion angle										
Queen (2011)[43]	Obs.	Early	6	−0.92	−0.12	−0.98, 0.74	0.791			
Peak extension angle										
Queen (2011)[43]	Obs.	Early	6	1.51	0.18	−0.68, 1.04	0.676			
Frontal plane range of motion										
Martz[52]	Obs.	Late	24	1.20	0.49	0.014, 0.97	0.043			
Peak adduction angle										
Queen (2011)[43]	Obs.	Early	6	−2.10	−0.83	−1.63, −0.04	0.047			
Peak abduction angle										
Queen (2011)[43]	Obs.	Early	6	2.31	0.59	−0.29, 1.46	0.189			
Kinetic gait characteristics										
Hip extension moment										
Queen (2013)[46]	Obs.	Early	6	0.28	0.78	−0.13, 1.69	0.093			
Queen (2013)[46]	Obs.	Late	52	0.05	0.15	−0.73, 1.03	0.741			

continued

TABLE VI (continued)

Characteristic and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value	Heterogeneity I²	Q	P Value
Hip adduction moment										
Queen (2013)[46]	Obs.	Early	6	−0.04	−0.13	−1.01, 0.58	0.775			
Queen (2013)[46]	Obs.	Late	52	0.03	0.16	−0.72, 1.04	0.720			
Queen (2014)[49]	Obs.	Late	52	−0.07	−0.43	−1.19, 0.33	0.267			
Random-effects model		Late		−0.03	−0.18	−0.75, 0.40	0.544	0.0%	0.995	0.319
Ground reaction force										
Queen (2011)[43]	Obs.	Early	6	0.01	0.00	−0.86, 0.86	0.997			
Queen (2013)[46]	Obs.	Early	6	−0.02	−0.07	−0.94, 0.81	0.882			
Random-effects model		Early		−0.02	−0.03	−0.65, 0.58	0.919	0.0%	0.012	0.913
Queen (2013)[46]	Obs.	Late	52	−0.01	−0.14	−1.02, 0.74	0.759			

*MD = mean difference, SMD = standardized mean difference, and Obs. = observational cohort study. †Positive values indicate that the posterior approach (control) had larger values.

was significantly larger in patients treated with the anterolateral approach at 6 weeks (p = 0.009), but no other significant differences were observed between approaches.

Lateral Versus Anterolateral Approach

Four observational cohort studies and 3 RCTs compared the effects of the lateral and anterolateral approaches. Individual and pooled effect sizes are presented in Table IX. Overall, there was a very large, significant pooled effect size, in favor of the lateral approach (SMD = 1.60; p = 0.05), suggesting that these patients had a longer step length at 6 weeks after surgery. In contrast to those observational data, a small, nonsignificant pooled effect size in the RCTs (SMD = 0.15) did not suggest this strong relationship at 12 weeks after surgery. No other significant differences were observed between approaches, and effect sizes varied.

Discussion

The present systematic review with meta-analysis suggests that few postoperative gait differences exist between surgical approaches used for performing THA. Despite the variety of techniques used to access the hip joint, which result in disruption of a variety of anatomical structures, the postoperative functional status of patients does not appear to be technique-specific. Few outcomes could be pooled across studies, but when pooling was possible, it did suggest that early and late step length were significantly greater after the posterior approach compared with the anterolateral approach and that early frontal plane hip moments were significantly greater after the posterior approach compared with the lateral approach. Despite moderate to large effect sizes (SMD = 0.46 to 0.70), the clinical importance of these differences is unclear. These potential mechanisms by which THA may alter postoperative gait patterns may be related to anatomic differences between surgical approaches, but without evaluation of neuromuscular function after surgery, these findings must be interpreted with caution and require further investigations.

Postoperative gait speed was the most commonly evaluated outcome after THA, with faster walking speeds attained after surgery. Previous reviews have indicated that gait speed is slower in patients with hip osteoarthritis before and after joint replacement when compared with healthy control populations[23,53]. However, the differences in postoperative gait speed between THA approaches were small and generally not significant (Tables IV through IX). Previously quantified meaningful benchmarks (minimal clinically important postoperative [MCIP] values) for gait after THA suggest that a walking speed of 1.34 m/s may be considered clinically important[53]. Although the current pooled effect sizes were not significant, Varin et al.[47] reported significantly faster speeds at late follow-up for patients treated with the anterior (compared with the lateral) approach (SMD = 0.93, MD = 0.17). Using the benchmarks proposed by Foucher[53], the postoperative gait speeds were not clinically meaningful (were less than the MCIP value) for the lateral approach (1.14 m/s). The anterior approach (1.31 m/s) nearly reached the threshold but lends support for better-maintained function using this less-invasive surgical technique. Importantly, no other spatiotemporal findings were reported as frequently, nor do clinical benchmarks exist to help interpret individual study findings. However, patients treated with the posterior approach had a significantly longer step length compared with patients treated with the anterolateral approach at early and late follow-up. Although the increased step length may play a role in observed trends toward increased gait speed after the posterior approach, similar increases were not observed for stride length.

Outcome measures involving joint angles and range of motion were even more inconsistent, and despite a comprehensive analysis of kinematic

TABLE VII Comparisons Between the Anterior (Control) and Lateral (Experimental) Approaches*

Characteristic and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value
Spatiotemporal gait characteristics							
Single-limb support							
Klausmeier[39]	Obs.	Early	6	−0.70	−0.20	−1.02, 0.62	0.635
Gait speed							
Klausmeier[39]	Obs.	Early	6	0.06	0.31	−0.52, 1.12	0.470
Varin[47]	Obs.	Late	38	0.17	0.93	0.28, 1.58	0.005
Stride length							
Klausmeier[39]	Obs.	Early	6	0.06	0.62	−0.22, 1.55	0.148
Step length							
Lugade[39]	Obs.	Early	6	0.02	0.20	−0.62, 1.02	0.634
Step width							
Lugade[39]	Obs.	Early	6	−0.02	−0.49	−1.32, 0.34	0.246
Kinematic gait characteristics							
Sagittal plane range of motion							
Klausmeier[39]	Obs.	Early	6	4.19	0.57	−0.27, 1.40	0.184
Varin[47]	Obs.	Late	38	2.90	0.49	−0.14, 1.12	0.126
Peak flexion angle							
Varin[47]	Obs.	Late	38	2.30	0.49	−0.14, 1.12	0.127
Peak extension angle							
Varin[47]	Obs.	Late	38	1.40	0.39	−0.24, 1.01	0.223
Frontal plane range of motion							
Klausmeier[39]	Obs.	Early	6	−0.36	−0.12	−0.94, 0.70	0.767
Peak adduction angle							
Varin[47]	Obs.	Late	38	−0.80	−0.30	−0.93, 0.32	0.343
Transverse plane range of motion							
Klausmeier[39]	Obs.	Early	6	−0.98	−0.08	−0.90, 0.74	0.846
Peak internal rotation angle							
Varin[47]	Obs.	Late	38	0.70	0.17	−0.46, 0.79	0.600
Pelvic tilt							
Varin[47]	Obs.	Late	38	0.90	0.71	0.07, 1.35	0.036
Pelvic obliquity							
Lugade[39]	Obs.	Early	6	1.16	0.55	−0.28, 1.38	0.197
Varin[47]	Obs.	Late	38	−0.90	−0.44	−1.07, 0.19	0.170
Kinetic gait characteristics							
Hip flexion moment							
Klausmeier[39]	Obs.	Early	6	0.02	0.11	−0.71, 0.93	0.786
Varin[47]	Obs.	Late	38	0.10	0.45	−0.17, 1.08	0.156
Hip extension moment							
Klausmeier[39]	Obs.	Early	6	0.15	0.50	−0.33, 1.34	0.234
Varin[47]	Obs.	Late	38	0.06	0.24	−0.38, 0.87	0.445
Hip adduction moment							
Klausmeier[39]	Obs.	Early	6	0.06	0.33	−0.49, 1.16	0.428
Varin[47]	Obs.	Late	38	−0.18	−1.03	−1.69, −0.37	0.002
Hip internal rotation moment							
Klausmeier[39]	Obs.	Early	6	0.06	0.47	−0.36, 1.30	0.267
Hip external rotation moment							
Klausmeier[39]	Obs.	Early	6	0.10	1.05	0.18, 1.92	0.019
Varin[47]	Obs.	Late	38	−0.03	−0.53	−1.16, 0.10	0.102

*MD = mean difference, SMD = standardized mean difference, and Obs. = observational cohort study. †Positive values indicate that the anterior approach (control) had larger values.

TABLE VIII Comparisons Between the Anterior (Control) and Anterolateral (Experimental) Approaches*

Characteristics and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value
Spatiotemporal gait characteristics							
Duration in stance							
Mayr[38]	RCT	Early	6	−0.45	−0.10	−0.84, 0.63	0.784
Single-limb support							
Mayr[38]	RCT	Early	6	1.15	0.23	−0.51, 0.96	0.544
Double-limb support							
Mayr[38]	RCT	Early	6	−1.65	−0.17	−0.91, 0.56	0.644
Gait speed							
Mayr[38]	RCT	Early	6	0.01	0.06	−0.67, 0.79	0.871
Stride length							
Mayr[38]	RCT	Early	6	0.00	0.00	−0.73, 0.73	1.000
Kinematic gait characteristics							
Sagittal plane range of motion							
Mayr[38]	RCT	Early	6	3.95	0.59	−0.16, 1.35	0.124
Peak flexion angle							
Mayr[38]	RCT	Early	6	1.29	0.22	−0.52, 0.96	0.558
Peak extension angle							
Mayr[38]	RCT	Early	6	1.25	0.23	−0.51, 0.97	0.538
Frontal plane range of motion							
Mayr[38]	RCT	Early	6	−0.36	−0.57	−1.33, 0.18	0.136
Peak adduction angle							
Mayr[38]	RCT	Early	6	−2.95	−0.69	−1.45, 0.07	0.074
Peak abduction angle							
Mayr[38]	RCT	Early	6	−2.42	−1.06	−1.84, −0.27	0.009
Transverse plane range of motion							
Mayr[38]	RCT	Early	6	−1.00	−0.15	−0.89, 0.59	0.692
Peak internal rotation angle							
Mayr[38]	RCT	Early	6	−2.21	−0.34	−1.08, 0.41	0.376
Peak external rotation angle							
Mayr[38]	RCT	Early	6	−0.26	−0.10	−0.84, 0.64	0.790
Pelvic tilt							
Mayr[38]	RCT	Early	6	−1.79	−0.55	−1.30, 0.21	0.154
Pelvic obliquity							
Mayr[38]	RCT	Early	6	−1.14	−0.65	−1.40, 0.11	0.095
Pelvic rotation							
Mayr[38]	RCT	Early	6	1.74	0.37	−0.38, 1.11	0.336

*MD = mean difference, SMD = standardized mean difference, and RCT = randomized controlled trial. †Positive values indicate that the anterior approach (control) had larger values.

outcomes, very few studies could be adequately pooled. Sagittal plane kinematics were most frequently reported in the individual studies, but only 2 studies reported significant differences between THA approaches. Using a clinical benchmark MCIP value of 30° for sagittal hip range of motion[53], patients treated with the posterior approach had significantly less range of motion (24°) than patients treated with the anterolateral approach (32°) in 1 study[52] and significantly less range of motion (36°) than patients treated with the anterior approach (46°) in another study[48]. The clinical importance of these differences requires further investigation but suggests that the less-invasive approaches may restore and maintain normal function in the sagittal plane[48,52]. However, the 8° to

TABLE IX Comparisons Between the Lateral (Control) and Anterolateral (Experimental) Approaches

Characteristic and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value	Heterogeneity		
								I^2	Q	P Value
Spatiotemporal gait characteristics										
Duration in stance										
Queen (2011)[43]	Obs.	Early	6	−2.26	−0.48	−1.35, 0.39	0.281			
Müller[44]	RCT	Early	12	−0.03	−0.19	−0.91, 0.52	0.597			
Martin[42]	RCT	Late	52	−1.30	−0.23	−0.66, 0.20	0.294			
Gait speed										
Queen (2011)[43]	Obs.	Early	6	−0.10	−0.45	−1.32, 0.42	0.309			
Queen (2013)[46]	Obs.	Early	6	−0.12	−0.65	−1.54, 0.26	0.161			
Nishimura[50]	Obs.	Early	9	−0.06	−0.35	−1.37, 0.67	0.498			
Random-effects model		Early		−0.09	−0.49	−1.03, 0.04	0.070	0.0%	0.187	0.911
Pospischill[41]	RCT	Early	12	0.06	0.24	−0.38, 0.86	0.447			
Müller[44]	RCT	Early	12	0.04	0.27	−0.45, 0.99	0.463			
Random-effects model		Early		0.05	0.25	−0.22, 0.72	0.291	0.0%	0.003	0.954
Queen (2013)[46]	Obs.	Late	52	0.00	0.00	−0.88, 0.88	1.000			
Nishimura[50]	Obs.	Late	28	−0.07	−0.51	−1.54, 0.52	0.330			
Random-effects model		Late		−0.05	−0.22	−0.88, 0.45	0.528	0.0%	0.552	0.458
Martin[42]	RCT	Late	52	0.10	0.10	−0.33, 0.53	0.637			
Stride length										
Queen (2011)[43]	Obs.	Early	6	0.02	0.22	−0.64, 1.08	0.610			
Queen (2013)[46]	Obs.	Early	6	0.07	0.52	−0.37, 1.41	0.257			
Nishimura[50]	Obs.	Early	9	−0.01	−0.06	−1.07, 0.96	0.908			
Random-effects model		Early		0.03	0.25	−0.28, 0.78	0.355	0.0%	0.702	0.704
Pospischill[41]	RCT	Early	12	0.03	0.22	−0.41, 0.84	0.497			
Queen (2013)[46]	Obs.	Late	52	0.00	0.00	−0.88, 0.88	1.000			
Nishimura[50]	Obs.	Late	28	0.01	0.07	−0.95, 1.08	0.897			
Random-effects model		Late		0.01	0.03	−0.64, 0.69	0.932	0.0%	0.010	0.922
Step length										
Queen (2011)[43]	Obs.	Early	6	0.05	0.81	−0.08, 1.70	0.073			
Queen (2013)[46]	Obs.	Early	6	0.02	2.48	1.32, 3.65	<0.001			
Random-effects model		Early		0.02	1.60	−0.03, 3.23	0.054	79.8%	4.957	0.026
Pospischill[41]	RCT	Early	12	0.02	0.27	−0.35, 0.89	0.397			
Müller[44]	RCT	Early	12	0.00	0.00	−0.72, 0.72	1.000			
Random-effects model		Early		0.01	0.15	−0.32, 0.62	0.523	0.0%	0.309	0.578
Queen (2013)[46]	Obs.	Late	52	0.00	0.00	−0.88, 0.88	1.000			
Martin[42]	RCT	Late	52	0.02	0.14	−0.29, 0.57	0.527			
Kinematic gait characteristics										
Sagittal plane range of motion										
Nishimura[50]	Obs.	Early	9	1.10	0.14	−0.88, 1.15	0.791			
Nishimura[50]	Obs.	Late	28	4.20	0.89	−0.18, 1.95	0.102			
Peak flexion angle										
Queen (2011)[43]	Obs.	Early	6	−2.13	−0.28	−1.14, 0.59	0.532			
Nishimura[50]	Obs.	Early	9	−0.30	−0.05	−1.06, 0.97	0.923			
Random-effects model		Early		−1.13	−0.18	−0.84, 0.48	0.590	0.0%	0.109	0.741
Pospischill[41]	RCT	Early	12	3.00	0.10	−0.52, 0.72	0.748			
Nishimura[50]	Obs.	Late	28	2.90	0.64	−0.40, 1.69	0.225			

continued

TABLE IX *(continued)*

Characteristic and Study	Design	Time	Weeks	MD†	SMD†	95% CI†	P Value	Heterogeneity I^2	Heterogeneity Q	Heterogeneity P Value
Peak extension angle										
Queen (2011)[43]	Obs.	Early	6	1.14	0.14	−0.72, 1.00	0.755			
Nishimura[50]	Obs.	Early	9	1.40	0.23	−0.78, 1.25	0.653			
Random-effects model		Early		1.29	0.18	−0.48, 0.83	0.597	0.0%	0.020	0.887
Pospischill[41]	RCT	Early	12	−2.00	−0.53	−1.16, 0.10	0.098			
Nishimura[50]	Obs.	Late	28	1.40	0.43	−0.60, 1.45	0.416			
Peak adduction angle										
Queen (2011)[43]	Obs.	Early	6	1.10	0.35	−0.52, 1.21	0.432			
Martin[42]	RCT	Late	52	0.70	0.19	−0.24, 0.62	0.393			
Peak abduction angle										
Queen (2011)[43]	Obs.	Early	6	0.99	0.24	−0.62, 1.10	0.587			
Pelvic tilt										
Nishimura[50]	Obs.	Early	9	0.20	0.11	−0.90, 1.13	0.829			
Pospischill[41]	RCT	Early	12	2.00	0.22	−0.41, 0.84	0.497			
Pelvic obliquity										
Nishimura[50]	Obs.	Late	28	0.30	0.26	−0.76, 1.28	0.616			
Martin[42]	RCT	Late	52	−0.10	−0.05	−0.48, 0.38	0.811			
Kinetic gait characteristics										
Hip extension moment										
Queen (2013)[46]	Obs.	Early	6	0.13	0.37	−0.52, 1.25	0.417			
Queen (2013)[46]	Obs..	Late	52	0.00	0.00	−0.88, 0.88	1.000			
Hip adduction moment										
Queen (2013)[46]	Obs.	Early	6	−0.17	−0.56	−1.45, 0.35	0.220			
Queen (2013)[46]	Obs.	Late	52	0.00	0.00	−0.88, 0.88	1.000			
Queen (2014)[49]	Obs.	Late	52	−0.01	−0.07	−0.89, 0.75	0.864			
Random-effects model		Late		−0.01	−0.04	−0.89, 0.75	0.907	0.0%	0.014	0.907
Ground reaction force										
Queen (2011)[43]	Obs.	Early	6	−0.04	−0.01	−0.86, 0.85	0.989			
Queen et al. (2013)[46]	Obs.	Early	6	−0.08	−0.30	−1.18, 0.59	0.511			
Random-effects model		Early		−0.08	−0.15	−0.76, 0.47	0.640	0.0%	0.213	0.645
Queen et al. (2013)[46]	Obs.	Late	52	0.00	0.00	−0.88, 0.88	1.000			

*MD = mean difference, SMD = standardized mean difference, Obs. = observational cohort study, and RCT = randomized controlled trial.
†Positive values indicate that the lateral approach (control) had larger values.

10° difference between approaches was not reflected in either the peak flexion or extension angles; thus, the mechanism for increased sagittal range of motion is unclear, possibly as a result of too few comparisons between these specific approaches plus a deficiency in studies assessing sagittal plane kinematics at long-term follow-up after use of the posterior approach. In the frontal and transverse planes, no pooled analyses could be performed and potential patterns were inconsistent between comparisons and at different follow-ups.

At the pelvis, greater pelvic obliquity was observed after use of the posterior approach (compared with the anterior and lateral approaches) (Tables IV and V). Considering the anatomical disturbances created by each approach, such greater obliquity might be expected after the lateral approach, which results in hip abductor muscle disruption. Furthermore, an RCT reported a moderate to large, significant effect size after the posterior, compared with the anterior, approach at late follow-up, which may further support the hypothesis that pelvic obliquity is more affected after the posterior approach. Establishment of a relationship between these findings and findings in healthy control populations remains limited because pelvic kinematics after THA have received little to no attention in previous reviews. In the sagittal and horizontal planes, limited findings were observed; 1 study alluded to greater anterior pelvic tilt (by approximately 1°) after the anterior compared with the lateral approach, but no other studies were available to refute or support that.

The most commonly reported parameter for understanding hip joint loading after THA was the frontal plane hip adduction moment; that moment was significantly greater after the posterior compared with the lateral approach, and the latter was significantly greater compared with the anterior approach at late follow-up. Using a clinical benchmark for the hip adduction moment of 4.2% of body weight times height (BW × Ht)[53], postoperative observations for the hip frontal plane moment were clinically meaningful (greater than the MCIP value) for the posterior approach (4.8% BW × Ht), not meaningful for the anterior approach (3.6% BW × Ht), and inconsistent for the lateral approach (3.7% to 4.6% BW × Ht)[36,47]. Patients with hip osteoarthritis have previously been shown to have lower hip adduction moments compared with healthy controls, and the size of the moments has further been associated with disease severity[54] and patient-reported pain[55]. The hip adduction moment after the posterior approach was higher by a clinically meaningful amount, which may suggest a shift toward a healthy gait pattern as the decreased soft-tissue damage involving the hip abductor muscles yields a greater likelihood of increased strength postoperatively[34,56-58]. Of note, the increased pelvic obliquity also observed after the posterior approach may play a mechanical role in the increased hip moment but could be representative of a less "healthy" gait pattern. Although no pooled analyses could be completed in the sagittal or transverse planes, the hip flexion, extension, and external rotation moments were greater after the anterior approach than after the posterior approach. The sagittal plane kinematics supported these positive findings for the anterior approach, highlighting key features of this surgical technique that include the absence of disruption to the anterior, posterior, or lateral muscle groups surrounding the hip.

Although significance was rarely achieved for individual and pooled effect sizes, the magnitude of the effect sizes cannot exclude the possible existence of some differences in gait biomechanics according to the type of surgical approach used. Using more consistent outcome measures for head-to-head comparisons of THA approaches and their impact on postoperative gait mechanics is needed before definitive conclusions can be made. We must also identify the most important parameter for return to function, which would enable better pooling across studies and a more in-depth analysis of the effects of hip replacement. Furthermore, our ability to interpret significant findings as clinically meaningful remains elusive because values that constitute acceptable or good gait outcomes after surgery remain somewhat undefined, with a few initial steps being made to establish clinical benchmarks[53]. Despite several challenges in our interpretation of the data, further consideration must also be given to postoperative rehabilitation protocols that are typically not standardized across studies and are often surgeon-specific. Inconsistencies between individual and pooled effect sizes are likely due to several limitations such as differences in data collection techniques and varied surgical skills. The number of participating surgeons was inconsistent across studies, and although a larger number of surgeons may increase the variability in the results, it would improve the external validity and therefore generalizability of the findings.

A limited number of RCTs were available for postoperative comparisons between approaches. As a result, nonrandomized observational cohorts were analyzed, with several of these failing to include preoperative data. Therefore, it should be recognized that some of the studies included in the present review may not have had equivalent groups at baseline. Nevertheless, the postoperative differences between groups were typically minimal at early and late follow-up, consistent with our conclusions that there was little difference between groups. Included manuscripts also rarely reported any surgically induced changes in leg length and femoral offset, which could have physiological implications for gait mechanics[16,59]. Including all 4 approaches for THA is a major strength of this study, and the study highlights the need for standardized outcomes when making future comparisons between techniques. Identifying key biomechanical outcomes will enable greater pooling of effect sizes to either support or refute the present findings.

In conclusion, we believe that this meta-analysis is the first to quantify overall effect sizes for the differences in postoperative gait mechanics between THA approaches. These findings suggest little difference between the approaches at early or late follow-up. We found a significant effect size at 6 weeks, in favor of the posterior approach over the lateral approach, for the hip adduction moment ($p = 0.020$). However, determining whether the reported postoperative gait value differences are clinically meaningful remains a substantial challenge for the interpretation of these findings. Identified gaps in the literature include defining the characteristics of patients who respond best to specific THA approaches, clarifying the relationship between changes in gait mechanics and soft-tissue disruptions in order to better understand potential biomechanical differences between techniques, and establishing clinical thresholds to better interpret postoperative outcomes.

Rebecca Moyer, PT, PhD[1],
Brent Lanting, MD[2],
Jacquelyn Marsh, PhD[3],
Abdulaziz Al-Jurayyan, MD, MSc[4],
Laura Churchill, MSc[3],
James Howard, MD[2],
Lyndsay Somerville, PhD[2]

[1]School of Physiotherapy, Faculty of Health, Dalhousie University, Halifax, Nova Scotia, Canada

[2]Department of Surgery, Schulich School of Medicine & Dentistry, University of Western Ontario, London, Ontario, Canada

[3]School of Physiotherapy, Faculty of Health Sciences, University of Western Ontario, London, Ontario, Canada

[4]College of Medicine, King Saud University, Riyadh, Saudi Arabia

E-mail address for R. Moyer: rebecca.moyer@dal.ca

ORCID iD for R. Moyer: 0000-0003-1719-4799

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