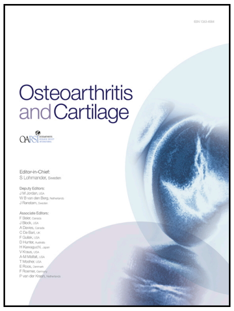
Archived at the Flinders Academic Commons:
http://dspace.flinders.edu.au/dspace/

‘This is the peer reviewed version of the following article: Bahl, J. S., Nelson, M. J., Taylor, M., Solomon, L. B., Arnold, J. B., & Thewlis, D. (2018). Biomechanical changes and recovery of gait function after total hip arthroplasty for osteoarthritis: a systematic review and meta-analysis. Osteoarthritis and Cartilage, 26(7), 847–863. https://doi.org/10.1016/j.joca.2018.02.897,

which has been published in final form at
https://doi.org/10.1016/j.joca.2018.02.897

© 2018 Elsevier. This manuscript version is made available under the CC-BY-NC-ND 4.0 license:
http://creativecommons.org/licenses/by-nc-nd/4.0/

Accepted Manuscript



# Biomechanical changes and recovery of gait function after total hip arthroplasty for osteoarthritis: a systematic review and meta-analysis

Jasvir S. Bahl, Maximillian J. Nelson, Mark Taylor, Lucian B. Solomon, John B. Arnold, Dominic Thewlis

PII: S1063-4584(18)31013-6

DOI: 10.1016/j.joca.2018.02.897

Reference: YJOCA 4182

To appear in: *Osteoarthritis and Cartilage*

Received Date: 28 August 2017

Revised Date: 4 February 2018

Accepted Date: 12 February 2018

Please cite this article as: Bahl JS, Nelson MJ, Taylor M, Solomon LB, Arnold JB, Thewlis D, Biomechanical changes and recovery of gait function after total hip arthroplasty for osteoarthritis: a systematic review and meta-analysis, *Osteoarthritis and Cartilage* (2018), doi: 10.1016/j.joca.2018.02.897.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

ACCEPTED MANUSCRIPT

# Biomechanical changes and recovery of gait function after total hip arthroplasty for osteoarthritis: a systematic review and meta-analysis

Jasvir S. Bahl [1], Maximillian J Nelson [1], Mark Taylor [2], Lucian B. Solomon [3, 4*], John B. Arnold [1*], Dominic Thewlis [3*]

[1]Alliance for Research in Exercise, Nutrition and Activity (ARENA), Sansom Institute for Health Research & School of Health Sciences, University of South Australia, Adelaide, Australia

[2]The Medical Device Research Institute, School of Computer Science, Engineering and Mathematics, Flinders University, Adelaide, South Australia

[3]Department of Orthopaedics and Trauma, Level 4 Bice Building, Royal Adelaide Hospital, North Terrace, Adelaide, South Australia, Australia

[4]Centre for Orthopaedic and Trauma Research, Discipline of Orthopaedics and Trauma, University of Adelaide, Adelaide, South Australia, Australia

*JBA, LBS and DT played equal roles in this research as joint senior authors.

**Running title:** Gait biomechanics after hip replacement

ACCEPTED MANUSCRIPT

**Contact details:**

Maximillian J Nelson: maximillian.nelson@mymail.unisa.edu.au

Mark Taylor: mark.taylor@flinders.edu.au

Lucian B. Solomon: Bogdan.Solomon@sa.gov.au

John B. Arnold: John.Arnold@unisa.edu.au

Dominic Thewlis: dominic.thewlis@adelaide.edu.au

**Corresponding author:**

Jasvir S Bahl, Alliance for Research in Exercise, Nutrition and Activity (ARENA), Sansom Institute for Health Research, University of South Australia, GPO Box 2471, Adelaide, Australia 5001 , Email: jasvir.bahl@mymail.unisa.edu.au, Phone: +61 8 8302 1305

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

## Objective

To determine the change in walking gait biomechanics after total hip arthroplasty (THA) for osteoarthritis (OA) compared to the pre-operative gait status, and to compare the recovery of gait following THA with healthy individuals.

## Methods

Systematic review with meta-analysis of studies investigating changes in gait biomechanics after THA compared to (1) preoperative levels and (2) healthy individuals. Data were pooled at commonly reported time points and standardised mean differences (SMDs) were calculated in meta-analyses for spatiotemporal, kinematic and kinetic parameters.

## Results

Seventy-four studies with a total of 2477 patients were included. At 6 weeks postoperative, increases were evident for walking speed (*SMD:* 0.32, 95% CI 0.14, 0.50), stride length (*SMD:* 0.40, 95% CI 0.19, 0.61), step length (*SMD:* 0.41, 95% CI 0.23, 0.59), and transverse plane hip range of motion (ROM) (*SMD:* 0.36, 95% CI 0.05, 0.67) compared to pre-operative gait. Sagittal, coronal and transverse hip ROM was significantly increased at 3 months (*SMDs:* 0.50 to 1.07). At 12 months postoperative, patients demonstrated deficits compared with healthy individuals for walking speed (*SMD:* -0.59, 95% CI -1.08 to -0.11), stride length (*SMD:* -1.27, 95% CI -1.63, -0.91), single limb support time (*SMD:* -0.82, 95% CI -1.23, -0.41) and sagittal plane hip ROM (*SMD:* -1.16, 95% CI -1.83, -0.49). Risk of bias scores ranged from seven to 24 out of 26.

## Conclusions

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Following THA for OA, early improvements were demonstrated for spatiotemporal and kinematic gait patterns compared to the pre-operative levels. Deficits were still observed in THA patients compared to healthy individuals at 12 months.

**Keywords**

osteoarthritis; hip replacement; arthroplasty; gait analysis; biomechanics

ACCEPTED MANUSCRIPT

## Introduction

Osteoarthritis (OA) of the hip is a common chronic condition responsible for significant pain and disability, with approximately 4 to 9% of adults over the age of 45 living with symptomatic hip OA [1, 2]. Diagnosis of symptomatic OA is the principal indication for total hip arthroplasty (THA), which is the treatment for individuals with end-stage OA when conservative therapies to manage symptoms have been exhausted. The demand for THA is estimated to rise substantially in the next decade, to approximately half a million primary THAs per year by 2030 in the United States [3]. Hip OA commonly affects a patient's function causing difficulty in walking where altered gait biomechanics are observed, particularly in individuals with severe stage disease who are candidates for THA [4]. Whilst THA is a successful procedure, attributed to the long-term survivorship of the implant and alleviation of chronic joint pain, aberrant pre-operative gait patterns may persist following THA, despite improvements in self-reported measures of pain and physical function [5, 6].

Two recent systematic reviews [7, 8] compared outcomes in walking gait following primary THA to that of healthy individuals and identified lower walking speed and stride length, lower sagittal and coronal plane hip joint range of motion, and lower peak hip abduction moment. Whilst these reviews provide a recent comparison of THA patients to that of healthy individuals, the pre-operative functional status of patients were not considered. The nature of gait abnormalities prior to the joint replacement must be considered due to the association between pre- and post-operative gait status [9]. Furthermore, reporting of post-operative gait abnormalities compared with healthy individuals may inadequately represent the changes after THA if relative change to pre-operative status is not considered as end-stage OA patients present with altered gait kinematics compared to healthy individuals

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

which may persist following surgery [5]. A range of time points, from 6 weeks to 24 months [10,11] have been used to investigate changes in gait biomechanics following THA for OA. To date, no review has synthesised the available evidence at commonly reported time points to identify the change from pre- to post-operative gait in people with OA following THA, and compare the results to healthy individuals to better understand the trajectory of change and recovery in gait function after THA. Therefore, the aims of this systematic review were to determine the change in gait biomechanics after THA compared to the pre-operative gait status; and to compare the recovery of gait following THA with healthy individuals.

## Methods

The findings of this review are reported in accordance with the Preferred Reporting Items for Systematic Reviews and meta-analyses (PRISMA) statement guidelines (Supplementary File 1) [13]. The protocol for the review was registered with the International Prospective register for Systematic Reviews (PROSPERO; registration no. CRD 42016035904).

### *Search strategy*

The PICO (Population, Intervention, Comparison and Outcome) framework was used to define the search strategy, in consultation with an academic librarian [14]. An electronic search of the following databases was performed with no date restrictions: PubMed, MEDLINE, CINAHL, The Cochrane Library, Embase, Scopus, Web of science, SportDiscus and Health collection. Keywords were matched with exploded MeSH terms to generate themes around total hip arthroplasty, biomechanics and gait (Supplementary File 2). Variations of electromyography and stair climbing were included as an outcome in the search as it was anticipated walking gait data might be included in studies of this kind. Database searching was performed by two authors (JB and JA) and agreement was required on the number of

ACCEPTED MANUSCRIPT

articles retrieved from each database before proceeding. Search alerts were created for each database to identify articles published after the initial search (up to January 1, 2017). Conference abstracts and reference lists of review and final included articles were manually searched to identify additional articles. Citations retrieved from the searches were uploaded to an online systematic review platform (Covidence) [15] for screening. Two reviewers (JB and MN) independently screened titles and abstracts and any conflicts were resolved by discussion, or by the opinion of a third researcher (JA) if consensus was not reached. Titles that met the eligibility criteria were then obtained as full manuscripts and reviewed independently by two reviewers (JB and MN). Disagreements were managed using the same process from the screening stage.

### *Eligibility criteria*

Articles were eligible for inclusion in this review when they satisfied the following criteria: (1) adults aged ≥18 years undergoing primary unilateral THA; (2) osteoarthritis was the primary indication for THA; (3) studies reporting the change in gait biomechanics (spatiotemporal, kinematics, kinetics) from pre- to post-operative or comparing THA patients following surgery to matched healthy individuals; (4) 2D or 3D motion analysis techniques (including ground reaction forces) were used to measure level walking at a self-selected speed; and (5) participants could perform the task unaided. Studies using motion capture systems, force platforms, accelerometers, instrumented treadmills or instrumented shoes were all included in this review. Spatiotemporal data collected from a hand-held timepiece (e.g. stopwatch) were excluded. Studies investigating the effect of physical rehabilitation on gait outcomes were excluded unless they included a conventional THA group who did not receive the intervention. Studies including participants who did not

ACCEPTED MANUSCRIPT

undergo THA (e.g. hip resurfacing) or participants with a history of other lower limb joint disease or surgeries (knee, ankle or contralateral hip) were not eligible.

*Outcome measures and data extraction*

A custom data-extraction spreadsheet was used to extract numerical data from all studies. The first author extracted the data (JSB), and a second author (JBA) verified the data were extracted accurately from the studies that were used in the meta-analysis. The primary outcome measures for this review were spatiotemporal, kinematic (joint angles) and kinetic parameters (e.g. external joint moments) reported during level walking. Means and standard deviations for all gait parameters were extracted for the pre-operative and follow-up time points, and from healthy control groups, when available. Extraction of joint kinematic and kinetic parameters were limited to the affected hip. The following information on patient and surgical characteristics was also extracted from each study: study design, sample size, age, gender, BMI, severity of osteoarthritis, and surgical approach.

*Data synthesis and analysis*

As numerous gait variables across multiple time points were expected, a structured process was undertaken to synthesise the results on the most commonly reported variables and time-points. Studies typically report a mean follow-up or multiple post-operative time points at six weeks, three months, six months and 12 months. Where studies reported a mean that was close to these time points (within one week for time points <6 months, and 3 months for time points >6 months) data were merged to the closest common time-point to facilitate comparison across studies. No studies were excluded during this process.

ACCEPTED MANUSCRIPT

When adequate data were reported, standardized mean differences (SMDs) were calculated using the pooled standard deviation for the biomechanical parameters between either the pre and post-operative time points (preoperative as the reference) or postoperative versus control group. Where not available, the standard error of the mean difference were estimated from *P* values using the equivalent T-statistic [16]. When this was not possible, the standard error of the mean difference was estimated using the most conservative correlation estimate from other studies [16], and the stability of this approach was assessed through a sensitivity analysis where the correlation estimate was set to zero to determine the impact on the magnitude of the pooled effect. Where study results were reported as medians and ranges or interquartile ranges, authors were contacted twice to obtain the mean and standard deviation (SD). When not provided, data were transformed to the mean and SD [17]. For the meta-analysis, pooled estimates and 95% confidence intervals (CI) for standardised mean differences were calculated using a random effects model in Review Manager software (RevMan, v5.2, Cochrane Collaboration, Oxford UK). Statistical significance was set at $P < 0.05$. All data were extracted and the pooled effect size estimates were computed when at least two studies reported the same gait variable at the same time point. The magnitude of the overall effect was quantified as trivial (<0.2), small (0.2-0.6), moderate (0.61-1.2), large (1.21-2.0) and very large (>2.0) [17]. Where studies presented data on more than one surgical approach instead of the entire THA cohort, a separate effect size was determined for each surgical group [17].

Heterogeneity was assessed using the $I^2$ and Cochran's Q statistics [18]. Where heterogeneity was statistically significant ($P < 0.05$), potential explanatory variables contributing to heterogeneity were assessed using linear regression, which was performed using six study

ACCEPTED MANUSCRIPT

characteristics identified *a priori* including age, BMI, sample size, surgical approach, gender and risk of bias score. The regression was only performed when ≥ 10 studies reported on a gait parameter at a time point [19]. Potential publication bias was examined using contour enhanced funnel plots and Egger's regression test using STATA (v14, Statacorp, USA).

*Methodological risk of bias*

Methodological risk of bias of studies was performed through merging three established checklists specific to gait analysis and surgical intervention studies (Supplementary File 4) [20, 21, 22]. The recommended scoring criteria from each tool were maintained resulting in a total of 20 items with a possible maximum score range of 0 to 26, with higher scores indicating a reduced risk of bias. The scoring was carried out by two independent reviewers (JB and MN), with any disagreements resolved with the opinion of a third reviewer if required. Inter-rater agreement for each item of the risk of bias tool was evaluated using the Kappa (κ) statistic. The risk of bias scores was included in the meta-regression to investigate if study bias contributed to heterogeneity. Based on the results of the meta-analysis (effect size), statistical heterogeneity ($I^2$) and risk of bias scores, of the strength of evidence for changes in each outcome variable at each time point was designated as per Van Tulder et al 2003 [23]: (1) strong evidence derived from three or more studies, including a minimum of two high-quality studies that were statistically homogenous ($I^2$ P ≥ 0.05); (2) moderate evidence derived from multiple studies that were statistically heterogeneous and where the pooled result was statistically significant, including at least one high-quality study from the risk of bias score; or from multiple moderate or low-quality studies which were statistically homogenous; (3) limited evidence provided by results from one high-quality study or multiple moderate-quality or low-quality studies that are statistically heterogeneous; (4)

ACCEPTED MANUSCRIPT

very limited evidence provided by results from one moderate-quality or low-quality study; and (5) no evidence where the pooled effect was insignificant and derived from multiple statistically heterogeneous studies (regardless of study quality from the risk of bias score).

## Results

### *Study selection and characteristics*

The electronic database search yielded 3415 articles. After applying the eligibility criteria and searching of reference lists, 74 studies were retained and 46 were included in the meta-analysis (Figure 1). Of the 74 included studies, 21 were prospective cohort studies, 21 case series studies, 29 case-control studies, and three randomised controlled trials (Table 1).

### *Patient and surgical characteristics*

There were 2477 patients from 74 studies with a mean age of 59.7 SD 7.4 years, body mass index (BMI) of 28.7 SD 3.6 kg/m$^2$ and 46% were female (Table 1). Post-operative follow-up ranged from 2 days to 6 years, with the most common time-points being 6 weeks, 3 months, 6 months, 12 months and 24 months. Only two studies [24, 25] reported the radiographic severity of OA prior to surgery [26]. The direct lateral and posterior surgical approaches were the most frequently used among the included studies (n=17 and n=16, respectively), followed by the anterolateral (n=13) and direct anterior (n=10).

### *Outcome measures*

A total of 20 spatiotemporal, 56 kinematic and 54 kinetic variables were identified (Figure 1). A total of 9 spatiotemporal and 6 kinematic variables met the requirements for meta-analysis in pre-post comparisons, while 8 variables for both domains met the criteria for post versus control. Only one kinetic variable was reported by ≥2 studies comparing

ACCEPTED MANUSCRIPT

postoperative THA patients to healthy controls (peak hip abduction moment). Five authors provided extra data upon request [27, 28, 29, 30, 31]. A summary of findings for each gait parameter in the meta-analysis at each time-point is provided in Table 2, with detailed information on the magnitude of effects and strength of evidence provided below.

*Spatiotemporal: comparison to pre-operative level*

Pooled data indicated there was moderate evidence of increased walking speed at 6 weeks (SMD: 0.32, P = 0.0006), 3 months (SMD: 0.78, P < 0.001) and 6 months (SMD: 0.97, P < 0.001), with large changes at 12 months (SMD: 1.28, P < 0.001) (Figure 2A). At 6 weeks, there was a small change in step length (SMD 0.41, P <0.001) (Figure 3A) and stride length (SMD: 0.40, P < 0.001) (Supplementary File 3), which was also present at 3 months (SMD: 0.52, P < 0.001; and SMD: 0.63, P < 0.001), with larger changes in step length at 6 months (SMD: 0.90, P < 0.001). There were trivial changes in step width at 6 weeks (SMD: -0.07, P = 0.57) and 3 months (SMD: 0.02, P = 0.96), with moderate evidence from five studies to suggest that cadence did not change at 6 months (SMD: -0.08, P = 0.87) (Supplementary File 3).

*Spatiotemporal: comparison to controls*

At 6 weeks post-THA there was moderate evidence demonstrating a large deficit in walking speed in THA patients compared with healthy individuals (SMD: -1.81, P < 0.001), which persisted but reduced in magnitude at 3 months (SMD: -1.22, P < 0.001), 6 months (SMD: -0.69, P < 0.001), and 12 months (SMD: -0.59, P = 0.02). Two studies provided limited evidence of a small deficit in walking speed at 24 months (SMD: -0.57, P < 0.007) (Figure 2B).

Deficits of reducing magnitude were observed in step length compared to healthy individuals at 6 weeks (SMD: -1.36, P < 0.001), 3 months (SMD: -0.88, P < 0.001), and 6

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

months (SMD: -0.35, P = 0.04), also persisting at 12 months post-THA (SMD: -0.54, P = 0.25) (Figure 3B). Marked deficits in stride length were also evident, with large effect sizes at 6 weeks (SMD: -1.90, P < 0.001) and 3 months (SMD: -1.60, P < 0.001) with a large improvement in THA patients between 3 and 6 months, but still a moderate deficit at 6 months (SMD: -0.78, P < 0.001). However, the same magnitude was not observed as compared to healthy individuals at 12 months (SMD: -1.27, P < 0.001).

Three studies provided moderate evidence for a very large increase in double support time at 6 weeks (SMD: 2.22, P < 0.03), however, patients were comparable to healthy individuals at 3 months (SMD: -0.28, P = 0.77), 6 months (SMD: 0.18, P = 0.60), and 12 months (SMD: -0.38, P = 0.10). Large increases in step width compared to healthy controls were evident at 6 weeks (SMD: 1.33, P < 0.001) and 3 months (SMD: 1.90, P = 0.004).

*Kinematic: comparison to pre-operative level*

Moderate evidence from four studies demonstrated small changes in sagittal plane hip ROM compared to pre-operative level at 6 weeks (SMD: 0.49, P = 0.22), with a moderate increase at 3 months (SMD: 1.07, P = 0.006) (Figure 4A). There was no change in coronal plane hip ROM at 6 weeks (SMD: 0.33, P = 0.22) and 12 months (SMD: 0.33, P = 0.22), with moderate evidence of a significant increase at 3 months (SMD: 1.03, P = 0.01) (Figure 5A). Pooled results indicated a small increase in transverse plane hip ROM at 6 weeks (SMD: 0.36, P = 0.02), 3 months (SMD: 0.50; P = 0.05) and 12 months (SMD: 0.36, P = 0.02) (Supplementary File 3). Two studies provided moderate evidence of a small decrease in peak hip abduction angle at 3 months (SMD: -0.39, P < 0.001). Moderate evidence indicated no significant change in peak hip flexion at 3 months (SMD: 0.16, P = 0.63) and coronal plane pelvic obliquity angle at 6 months (SMD: -0.81, P = 0.38) (Supplementary File 3).

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

*Kinematic: comparison to controls*

Very large deficits in sagittal plane hip ROM compared to healthy individuals were observed at 6 weeks (SMD: -2.59, P < 0.001), decreasing in magnitude but persisting at 3 months (SMD: -1.88, P < 0.001), 6 months (SMD: -1.33, P < 0.001) and 12 months (SMD: -1.16, P < 0.001) (Figure 4B). This also occurred for coronal plane hip ROM, with large deficits at 6 weeks (SMD: -1.76, P < 0.001) and 3 months (SMD: -1.41, P < 0.001) (Figure 5B). There were negligible changes in transverse plane hip ROM compared to healthy individuals at 6 weeks (SMD: 0.18, P = 0.39) and 3 months (SMD: 0.26, P = 0.56).

Moderate evidence from five studies demonstrated a significant increase in sagittal plane pelvis ROM compared to healthy individuals with a small effect at 12 months (SMD: 0.48, P = 0.05). THA patients were comparable to healthy individuals for coronal plane pelvic obliquity angle at 3 months (SMD: -0.20, P = 0.90), 6 months (SMD: 0.28, P = 0.67), and 12 months (SMD: 0.09, P = 0.75) (Supplementary File 3).

*Kinetic: comparison to controls*

Four studies provided moderate evidence demonstrating THA patients were comparable to healthy individuals for peak hip abduction moment at 3 months (SMD: 0.02, P = 0.92). There was insufficient data to compare the change from pre-operative status.

*Meta-regression and sensitivity analysis*

Pooled analyses for velocity (6 weeks, 3 and 12 months), as well as step length and stride length (6 weeks), indicated high statistical heterogeneity (P < 0.05) with greater than 10 studies reporting data at each time point. Among these factors, there was an association with the velocity effect size and younger age at 3 months and 12 months.  There was an

ACCEPTED MANUSCRIPT

association between step length effect size and study sample size at 6 weeks. No association was found for BMI, anterior surgical approach, gender or risk of bias score (Table 3). The sensitivity analysis revealed no change in the magnitude of the overall effect and the level of significance when the correlation estimates were zero (Supplementary file 5).

*Risk of publication bias*

Egger's regression test demonstrated no evidence of publication bias for velocity at 6 weeks ($\beta = 1.04$, $P = 0.368$), 3 months ($\beta = 1.6$, $P = 0.144$), and 12 months ($\beta = 1.4$, $P = 0.361$) or for stride and step length at 6 weeks ($\beta = 2.00$, $P = 0.657$; $\beta = 2.46$, $P = 0.187$, respectively).

*Risk of methodological bias*

Inter-rater agreement for risk of bias scoring was high ($\kappa = 0.77$). Of a possible maximum 26 points, the mean risk of bias score across studies was 18, SD = 4 (range = 7 to 24). Inadequate reporting of the sampling methods for recruitment (item 4), post-operative rehabilitation protocol (item 9), and number and characteristics of patients lost to follow-up (item 19) was common. Full risk of bias scoring is provided in Supplementary File 4.

## Discussion

The aims of this systematic review were to determine the change in gait biomechanics after THA compared to the pre-operative gait status; and to compare the recovery of gait following THA with healthy individuals. This review identified evidence for moderate to large pre to post-operative changes from 6 weeks to 12 months in spatiotemporal and kinematic parameters. Compared to healthy individuals, although selected gait parameters appeared to normalise after THA, residual deficits in walking speed, stride length and sagittal plane hip ROM existed at 12 months postoperative.

ACCEPTED MANUSCRIPT

Relatively consistent improvements were demonstrated over time in walking velocity, step length and stride length following THA compared to pre-operative levels. The observed changes in gait velocity following surgery in this meta-analysis did not meet the meaningful clinically important improvements in gait velocity stated by Foucher et al. (2016) [32]. Early improvements after THA were evident for walking speed, step length, stride length, and single-limb support time at 6 weeks, with improvements relative to before surgery demonstrated up to 12 months. Despite these observed improvements in spatiotemporal parameters compared to the pre-operative status, patients were only comparable to healthy individuals for step length, which demonstrated early recovery and return to normal function from 6 weeks post-surgery. Importantly, despite early changes and significant improvements in walking speed for up to 12 months post-surgery, lower walking speed is still present at 12 months compared to healthy individuals. Step width was wider compared to healthy individuals at 6 weeks and 3 months indicating patients continue to demonstrate a wider based of support during gait after surgery.

The kinematic data revealed increases in sagittal plane hip ROM and transverse plane hip ROM compared to pre-operative function at 6 weeks and up to 12 months. Despite continuous improvements following THA for sagittal plane hip ROM, reduced hip ROM in THA patients compared to healthy individuals at 12 months was evident. This may be due to an increase in pelvis and/or trunk flexion developed as a strategy to avoid pain before surgery [34], and potentially maintained following THA [5]. Coronal plane hip abduction/adduction revealed no significant change from pre-operative status up to 12 months post THA, with a significantly lower coronal plane hip ROM compared to healthy individuals. Abnormal coronal plane hip kinematics following THA could be due to several reasons including muscle weakness in the affected limb due to pain and impaired function before surgery [33], and incision of the abductor muscles during surgery [34]. Pelvic obliquity ROM was comparable to healthy individuals from 3 months and maintained up to 12 months.

A meta-regression was performed to identify possible explanations for the observed heterogeneity in the gait parameters of velocity, stride length and step length. Only age was associated with effect size of walking speed at 3 months and 12 months post-operatively, indicating younger patients were associated with earlier recovery. The study sample size was related to effect size heterogeneity for step length at 6 weeks, with larger sample sizes showing a smaller effect for increased step length compared to pre-operative gait.

Despite previous systematic reviews describing the deficient gait parameters in patients following THA compared to healthy individuals [7, 8] the pre-operative gait was not considered to determine the trend in recovery. This meta-analysis has for the first time, concurrently mapped the recovery in gait biomechanics after THA and compared postoperative status to healthy controls up to 2 years after surgery. A greater number of longitudinal cohort studies with follow-up beyond 12 months are required to appropriately map the trajectory of recovery after THA and determine the effect of surgery on gait function in the long term. Furthermore, greater consistency of reporting of gait parameters would facilitate easier comparison across studies, particularly for kinetic gait parameters. Unfortunately inconsistency in reporting precluded meta-analysis of most joint moment parameters. A greater understanding the effect of THA on muscle function in future studies will shed light onto the mechanisms underlying the deficits in gait biomechanics identified in this review.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Certain limitations of this review should be acknowledged. First, all study designs were included in the review to determine the changes in gait biomechanics following THA and compared to healthy individuals. Therefore, this review is susceptible to bias through the inclusion of lower level study designs. However, we undertook an established grading of evidence that considers study risk of bias, magnitude of the effect size and heterogeneity to synthesise the findings. Second, the studies included to evaluate the change in gait from pre- to post-operative status were not synonymous with the studies included to compare post-operative gait to healthy individuals due to the limited number of longitudinal studies that included a control group. Therefore, direct comparison between the two separate analyses is cautioned. Some of the meta-analyses were based on a smaller number of studies of varying methodological quality, although the regression analyses indicated the risk of bias scores could not explain any observed heterogeneity. Finally, only studies published in English were included due to limited translation resources. Therefore it is uncertain if inclusion of non-English studies would alter the outcomes of the review.

## Conclusion

Compared with OA patients before surgery THA was successful in improving walking speed, step length, stride length, single-limb support time, sagittal and coronal plane hip ROM. Despite these observed improvements from pre-operative OA individuals, patients continued to demonstrate deficiencies compared to healthy individuals for walking speed, stride length, single limb support time and sagittal plane hip ROM at 12 months. Improved understanding of the trajectories of recovery in gait function after THA may assist in managing expectations for both patients and clinicians, with further research required to elucidate the impact of these impairments and relationships with clinical outcome.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

1. Kim C, Linsenmeyer KD, Vlad SC, Guermazi A, Clancy MM, Niu J, et al. Prevalence of radiographic and symptomatic hip osteoarthritis in an urban United States community: the Framingham osteoarthritis study. Arthritis & Rheumatology 2014; 66: 3013-3017.
2. Jordan JM, Helmick CG, Renner JB, Luta G, Dragomir AD, Woodard J, et al. Prevalence of hip symptoms and radiographic and symptomatic hip osteoarthritis in African Americans and Caucasians: the Johnston County Osteoarthritis Project. The Journal of rheumatology 2009; 36: 809-815.
3. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007; 89: 780-785.
4. Eitzen I, Fernandes L, Kallerud H, Nordsletten L, Knarr B, Risberg MA. Gait characteristics, symptoms, and function in persons with hip osteoarthritis: a longitudinal study with 6 to 7 years of follow-up. journal of orthopaedic & sports physical therapy 2015; 45: 539-549.
5. Foucher KC, Hurwitz DE, Wimmer MA. Preoperative gait adaptations persist one year after surgery in clinically well-functioning total hip replacement patients. J Biomech 2007; 40: 3432-3437.
6. Lindemann U, Becker C, Muche R, Aminian K, Dejnabadi H, Nikolaus T, et al. Gait analysis and WOMAC are complementary in assessing functional outcome in total hip replacement. Clinical Rehabilitation 2006; 20: 413-420.
7. Ewen AM, Stewart S, St Clair Gibson A, Kashyap SN, Caplan N. Post-operative gait analysis in total hip replacement patients-a review of current literature and meta-analysis. Gait Posture 2012; 36: 1-6.

ACCEPTED MANUSCRIPT

8. Kolk S, Minten MJ, van Bon GE, Rijnen WH, Geurts AC, Verdonschot N, et al. Gait and gait-related activities of daily living after total hip arthroplasty: a systematic review. Clinal Biomechanics 2014; 29: 705-718.

9. Foucher KC, Freels S. Preoperative factors associated with postoperative gait kinematics and kinetics after total hip arthroplasty. Osteoarthritis Cartilage 2015; 23: 1685-1694.

10. Queen RM, Butler RJ, Watters TS, Kelley SS, Attarian DE, Bolognesi MP. The effect of total hip arthroplasty surgical approach on postoperative gait mechanics. J Arthroplasty 2011; 26: 66-71.

11. Sicard-Rosenbaum L, Light KE, Behrman AL. Gait, lower extremity strength, and self-assessed mobility after hip arthroplasty. Journals of Gerontology Series a-Biological Sciences and Medical Sciences 2002; 57: M47-M51.

12. Perron M, Malouin F, Moffet H, McFadyen BJ. Three-dimensional gait analysis in women with a total hip arthroplasty. Clin Biomech (Bristol, Avon) 2000; 15: 504-515.

13. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. International journal of surgery 2010; 8: 336-341.

14. Schardt C, Adams MB, Owens T, Keitz S, Fontelo P. Utilization of the PICO framework to improve searching PubMed for clinical questions. BMC medical informatics and decision making 2007; 7: 16.

15. Veritas Health Innovation Ltd. Covidence systematic review software. Melbourne, Australia.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

16. Elbourne DR, Altman DG, Higgins JP, Curtin F, Worthington HV, Vail A. Meta-analyses involving cross-over trials: methodological issues. International journal of epidemiology 2002; 31: 140-149.

17. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. Medicine & Science in Sports & Exercise 2009; 41: 3-12.

18. Higgins J, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses [journal article as teaching resource, deposited by John Flynn]. British medical journal 2003; 327: 557-560.

19. Higgins JP, Green S. Cochrane handbook for systematic reviews of interventions. Volume 4, John Wiley & Sons 2011.

20. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. Journal of epidemiology and community health 1998; 52: 377-384.

21. Peters A, Galna B, Sangeux M, Morris M, Baker R. Quantification of soft tissue artifact in lower limb human motion analysis: a systematic review. Gait & posture 2010; 31: 1-8.

22. Sabharwal S, Patel NK, Bull AM, Reilly P. Surgical interventions for anterior shoulder instability in rugby players: A systematic review. World journal of orthopedics 2015; 6: 400.

23. Van Tulder M, Furlan A, Bombardier C, Bouter L, Group EBotCCBR. Updated method guidelines for systematic reviews in the Cochrane Collaboration Back Review Group. Spine 2003; 28: 1290-1299.

24. Colgan G, Walsh M, Bennett D, Rice J, O'Brien T. Gait analysis and hip extensor function early post total hip replacement. Journal of Orthopaedics 2016; 13: 171-176.

25. Kiss RM, Illyes A. Comparison of gait parameters in patients following total hip arthroplasty with a direct-lateral or antero-lateral surgical approach. Hum Mov Sci 2012; 31: 1302-1316.

26. Kellegren J, Lawrence J. Radiological assessment of osteoarthritis. Ann Rheum Dis 1957; 16: 494-501.

27. Agostini V, Ganio D, Facchin K, Cane L, Moreira Carneiro S, Knaflitz M. Gait parameters and muscle activation patterns at 3, 6 and 12 months after total hip arthroplasty. Journal of Arthroplasty 2014; 29: 1265-1272.

28. Bennett D, Humphreys L, O'Brien S, Kelly C, Orr JF, Beverland DE. Gait kinematics of age-stratified hip replacement patients-A large scale, long-term follow-up study. Gait and Posture 2008; 28: 194-200.

29. Casartelli NC, Item-Glatthorn JF, Bizzini M, Leunig M, Maffiuletti NA. Differences in gait characteristics between total hip, knee, and ankle arthroplasty patients: a six-month postoperative comparison. BMC Musculoskelet Disord 2013; 14: 176.

30. Maffiuletti NA, Impellizzeri FM, Widler K, Bizzini M, Kain MSH, Munzinger U, et al. Spatiotemporal Parameters of Gait After Total Hip Replacement: Anterior versus Posterior Approach. Orthopedic Clinics of North America 2009; 40: 407–415.

31. Tateuchi H, Tsukagoshi R, Fukumoto Y, Oda S, Ichihashi N. Dynamic hip joint stiffness in individuals with total hip arthroplasty: Relationships between hip impairments and dynamics of the other joints. Clinical Biomechanics 2011; 26: 598-604.

ACCEPTED MANUSCRIPT

32. Foucher KC. Identifying clinically meaningful benchmarks for gait improvement after total hip arthroplasty. Journal of Orthopaedic Research 2016; 34: 88-96.

33. Arokoski MH, Arokoski JP, Haara M, Kankaanpää M, Vesterinen M, Niemitukia LH, et al. Hip muscle strength and muscle cross sectional area in men with and without hip osteoarthritis. The Journal of rheumatology 2002; 29: 2185-2195.

34. Mayr E, Nogler M, Benedetti MG, Kessler O, Reinthaler A, Krismer M, et al. A prospective randomized assessment of earlier functional recovery in THA patients treated by minimally invasive direct anterior approach: a gait analysis study. Clin Biomech (Bristol, Avon) 2009; 24: 812-818.

35. Ajemian S, Thon D, Clare P, Kaul L, Zernicke RF, Loitz-Ramage B. Cane-assisted gait biomechanics and electromyography after total hip arthroplasty. Archives of Physical Medicine and Rehabilitation 2004; 85: 1966-1971.

36. Aminian K, Rezakhanlou K, De Andres E, Fritsch C, Leyvraz PF, Robert P. Temporal feature estimation during walking using miniature accelerometers: an analysis of gait improvement after hip arthroplasty. Medical & Biological Engineering & Computing 1999; 37: 686-691.

37. Atallah L, Wiik A, Lo B, Cobb JP, Amis AA, Yang GZ. Gait asymmetry detection in older adults using a light ear-worn sensor. Physiological Measurement 2014; 35: N29-N40.

38. Beaulieu ML, Lamontagne M, Beaule PE. Lower limb biomechanics during gait do not return to normal following total hip arthroplasty. Gait Posture 2010; 32: 269-273.

39. Behery OA, Foucher KC. Are Harris Hip Scores and Gait Mechanics Related Before and After THA? Clinical Orthopaedics and Related Research 2014; 472: 3452-3461.

ACCEPTED MANUSCRIPT

40. Bennett D, Ogonda L, Elliott D, Humphreys L, Beverland DE. Comparison of gait kinematics in patients receiving minimally invasive and traditional hip replacement surgery: a prospective blinded study. Gait Posture 2006; 23: 374-382.

41. Berman AT, Quinn RH, Zarro VJ. Quantitative gait analysis in unilateral and bilateral total hip replacements. Arch Phys Med Rehabil 1991; 72: 190-194.

42. Bhargava P, Shrivastava P, Nagariya S. Assessment of changes in gait parameters and vertical ground reaction forces after total hip arthroplasty. Indian J Orthop 2007; 41: 158-162.

43. Bianchi L, Anasetti F, Mondini A, La Bionda F, Giacometti Ceroni R, Zagra L. No differences in gait recovery after total hip arthroplasty with different head diameters: A prospective randomised study. HIP International 2012; 22 (4): 474.

44. Bouffard V, Nantel J, Therrien M, Vendittoli PA, Lavigne M, Prince F. Center of Mass Compensation during Gait in Hip Arthroplasty Patients: Comparison between Large Diameter Head Total Hip Arthroplasty and Hip Resurfacing. Rehabil Res Pract 2011; 2011: 586412.

45. Cichy B, Wilk M, Sliwinski Z. Changes in gait parameters in total hip arthroplasty patients before and after surgery. Medical Science Monitor 2008; 14: CR159-CR169.

46. da Cunha BM, Gava AD, de Oliveira SB, de David AC, dos Santos-Neto LL. Vitamin d is related to gait recovery after total hip arthroplasty: A prospective analysis. Gait & Posture 2016; 50: 96-101.

47. Foucher KC, Thorp LE, Orozco D, Hildebrand M, Wimmer MA. Differences in preferred walking speeds in a gait laboratory compared with the real world after total hip replacement. Arch Phys Med Rehabil 2010; 91: 1390-1395.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

48. Foucher KC, Wimmer MA, Moisio KC, Hildebrand M, Berli MC, Walker MR, et al. Time course and extent of functional recovery during the first postoperative year after minimally invasive total hip arthroplasty with two different surgical approaches--a randomized controlled trial. J Biomech 2011; 44: 372-378.

49. Holnapy G, Illyes A, Kiss RM. Impact of the method of exposure in total hip arthroplasty on the variability of gait in the first 6 months of the postoperative period. Journal of Electromyography and Kinesiology 2013; 23: 966-976.

50. Horstmann T, Listringhaus R, Haase GB, Grau S, Mundermann A. Changes in gait patterns and muscle activity following total hip arthroplasty: A six-month follow-up. Clinical Biomechanics 2013; 28: 762-769.

51. Husby VS, Helgerud J, Bjorgen S, Husby OS, Benum P, Hoff J. Early Maximal Strength Training Is an Efficient Treatment for Patients Operated With Total Hip Arthroplasty. Archives of Physical Medicine and Rehabilitation 2009; 90: 1658-1667.

52. Isobe Y, Okuno M, Otsuki T, Yamamoto K. Clinical study on arthroplasties for osteoarthritic hip by quantitative gait analysis - Comparison between total hip arthroplasty and bipolar endoprosthetic arthroplasty. Bio-Medical Materials and Engineering 1998; 8: 167-175.

53. Jensen C, Penny JO, Nielsen DB, Overgaard S, Holsgaard-Larsen A. Quantifying Gait Quality in Patients with Large-Head and Conventional Total Hip Arthroplasty-A Prospective Cohort Study. Journal of Arthroplasty 2015; 30: 2343-U2425.

54. Jensen C, Rosenlund S, Nielsen DB, Overgaard S, Holsgaard-Larsen A. Can gait deviation index be used effectively for the evaluation of gait pathology in total hip arthroplasty? an explorative randomized trial.  Osteoarthritis and cartilage, vol. 222014:S85-s86.

ACCEPTED MANUSCRIPT

55. Judd DL, Winters JD, Stevens-Lapsley JE, Christiansen CL. Effects of neuromuscular reeducation on hip mechanics and functional performance in patients after total hip arthroplasty: A case series. Clin Biomech 2015; 32: 49-55.

56. Kanzaki H, Nankaku M, Kawanabe K, Nakamura T, Shimada T, Yoneda T, et al. The Recovery of the Walking Ability of Patients at Early Stages after Total Hip Arthroplasty from the Perspective of the Displacement of the Center of Gravity. Journal of Physical Therapy Science 2008; 20: 225-232.

57. Klausmeier V, Lugade V, Jewett BA, Collis DK, Chou LS. Is There Faster Recovery With an Anterior or Anterolateral THA? A Pilot Study. Clinical Orthopaedics and Related Research 2010; 468: 533-541.

58. Krych AJ, Pagnano MW, Coleman Wood K, Meneghini RM, Kaufman K. No strength or gait benefit of two-incision THA: a brief followup at 1 year. Clinical orthopaedics and related research, vol. 4692011:1110-1118.

59. Krych AJ, Pagnano MW, Wood KC, Meneghini RM, Kaufmann K. No benefit of the two-incision THA over mini-posterior THA: a pilot study of strength and gait. Clinical orthopaedics and related research, vol. 4682010:565-570.

60. Lavigne M, Ganapathi M, Nantel J, Prince F, Roy A, Therrien M, et al. Randomized double-blinded study comparing clinical outcome and gait characteristics after large diameter head total hip arthroplasty (LDH-THA) and hip resurfacing (HR). Orthopaedic Proceedings, vol. 92: Orthopaedic Proceedings 2010:523-523.

61. Lenaerts G, Mulier M, Spaepen A, Van der Perre G, Jonkers I. Aberrant pelvis and hip kinematics impair hip loading before and after total hip replacement. Gait Posture 2009; 30: 296-302.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

62. Li JY, McWilliams AB, Jin ZM, Fisher J, Stone MH, Redmond AC, et al. Unilateral total hip replacement patients with symptomatic leg length inequality have abnormal hip biomechanics during walking. Clinical Biomechanics 2015; 30: 513-519.

63. Li J, Redmond AC, Jin Z, Fisher J, Stone MH, Stewart TD. Hip contact forces in asymptomatic total hip replacement patients differ from normal healthy individuals: Implications for preclinical testing. Clinical Biomechanics 2014; 29: 747-751.

64. Loizeau J, Allard P, Duhaime M, Landjerit B. Bilateral gait patterns in subjects fitted with a total hip prosthesis. Arch Phys Med Rehabil 1995; 76: 552-557.

65. Lugade V, Klausmeier V, Jewett B, Collis D, Chou LS. Short-term recovery of balance control after total hip arthroplasty. Clinical Orthopaedics and Related Research 2008; 466: 3051-3058.

66. Lugade V, Wu A, Jewett B, Collis D, Chou LS. Gait asymmetry following an anterior and anterolateral approach to total hip arthroplasty. Clinical Biomechanics 2010; 25: 675-680.

67. Madsen MS, Ritter MA, Morris HH, Meding JB, Berend ME, Faris PM, et al. The effect of total hip arthroplasty surgical approach on gait. J Orthop Res 2004; 22: 44-50.

68. Mantovani G, Lamontagne M, Varin D, Cerulli GG, Beaule PE. Comparison of total hip arthroplasty surgical approaches by Principal Component Analysis. Journal of Biomechanics 2012; 45: 2109-2115.

69. Martinez-Ramirez A, Weenk D, Lecumberri P, Verdonschot N, Pakvis D, Veltink PH. Assessment of asymmetric leg loading before and after total hip arthroplasty using instrumented shoes. Journal of NeuroEngineering and Rehabilitation 2014; 11 (1) (no pagination).

ACCEPTED MANUSCRIPT

70. McCrory JL, White SC, Lifeso RM. Vertical ground reaction forces: objective measures of gait following hip arthroplasty. Gait Posture 2001; 14: 104-109.

71. Meneghini RM, Smits SA, Swinford RR, Bahamonde RE. A randomized, prospective study of 3 minimally invasive surgical approaches in total hip arthroplasty: comprehensive gait analysis. The Journal of arthroplasty, vol. 232008:68-73.

72. Miki H, Sugano N, Hagio K, Nishii T, Kawakami H, Kakimoto A, et al. Recovery of walking speed and symmetrical movement of the pelvis and lower extremity joints after unilateral THA. Journal of Biomechanics 2004; 37: 443-455.

73. Muller M, Schwachmeyer V, Tohtz S, Taylor WR, Duda GN, Perka C, et al. The direct lateral approach: impact on gait patterns, foot progression angle and pain in comparison with a minimally invasive anterolateral approach. Arch Orthop Trauma Surg 2012; 132: 725-731.

74. Nankaku M, Akiyama H, Kanzaki H, Kakinoki R. Effects of vertical motion of the centre of mass on walking efficiency in the early stages after total hip arthroplasty. Hip International 2012; 22: 521-526.

75. Nankaku M, Tsuboyama T, Kakinoki R, Kawanabe K, Kanzaki H, Mito Y, et al. Gait analysis of patients in early stages after total hip arthroplasty: effect of lateral trunk displacement on walking efficiency. Journal of Orthopaedic Science 2007; 12: 550-554.

76. Nantel J, Termoz N, Vendittoli PA, Lavigne M, Prince F. Gait patterns after total hip arthroplasty and surface replacement arthroplasty. Archives of physical medicine and rehabilitation, vol. 902009:463-469.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

77. Queen RM, Schaeffer JF, Butler RJ, Berasi CC, Kelley SS, Attarian DE, et al. Does Surgical Approach During Total Hip Arthroplasty Alter Gait Recovery During the First Year Following Surgery? Journal of Arthroplasty 2013; 28: 1639-1643.

78. Rathod PA, Orishimo KF, Kremenic IJ, Deshmukh AJ, Rodriguez JA. Similar Improvement in Gait Parameters Following Direct Anterior & Posterior Approach Total Hip Arthroplasty. Journal of Arthroplasty 2014; 29: 1261-1264.

79. Reininga IHF, Stevens M, Wagenmakers R, Boerboom AL, Groothoff JW, Bulstra SK, et al. Comparison of Gait in Patients Following a Computer-Navigated Minimally Invasive Anterior Approach and a Conventional Posterolateral Approach for Total Hip Arthroplasty: A Randomized Controlled Trial. Journal of Orthopaedic Research 2013; 31: 288-294.

80. Rosenberg AG. Gait abnormalities following surface hip replacement: a comparative study of patients with surface and total hip replacements. Proceedings of the Institute of Medicine of Chicago 1982; 35: 77-82.

81. Rosler J, Perka C. The effect of anatomical positional relationships on kinetic parameters after total hip replacement. International Orthopaedics 2000; 24: 23-27.

82. Shrader MW, Bhowmik-Stoker M, Jacofsky MC, Jacofsky DJ. Gait and Stair Function in Total and Resurfacing Hip Arthroplasty: A Pilot Study. Clinical Orthopaedics and Related Research 2009; 467: 1476-1484.

83. Stansfield BW, Nicol AC. Hip joint contact forces in normal subjects and subjects with total hip prostheses: walking and stair and ramp negotiation. Clinical Biomechanics 2002; 17: 130-139.

ACCEPTED MANUSCRIPT

84. Talis VL, Grishin AA, Solopova IA, Oskanyan TL, Belenky VE, Ivanenko YP. Asymmetric leg loading during sit-to-stand, walking and quiet standing in patients after unilateral total hip replacement surgery. Clinical Biomechanics 2008; 23: 424-433.

85. Tanaka R, Shigematsu M, Motooka T, Mawatari M, Hotokebuchi T. Factors influencing the improvement of gait ability after total hip arthroplasty. Journal of Arthroplasty 2010; 25: 982-985.

86. van den Akker-Scheek I, Stevens M, Bulstra SK, Groothoff JW, van Horn JR, Zijlstra W. Recovery of gait after short-stay total hip arthroplasty. Archives of Physical Medicine and Rehabilitation 2007; 88: 361-367.

87. Varin D, Lamontagne M, Beaule PE. Does the anterior approach for tha provide closer-to-normal lower-limb motion? Journal of Arthroplasty 2013; 28: 1401-1407.

88. Vogt L, Banzer W, Pfeifer K, Galm R. Muscle activation pattern of hip arthroplasty patients in walking. Research in Sports Medicine 2004; 12: 191-199.

89. Vogt L, Brettmann K, Pfeifer K, Banzer W. Walking patterns of hip arthroplasty patients: Some observations on the medio-lateral excursions of the trunk. Disability and Rehabilitation 2003; 25: 309-317.

90. Waldman G, Foucher KC. Clinical and biomechanical characteristics of total hip arthroplasty responders and nonresponders. Arthritis and Rheumatism 2012; 64: S346-S347.

91. Ward SR, Jones RE, Long WT, Thomas DJ, Dorr LD. Functional recovery of muscles after minimally invasive total hip arthroplasty. Instr Course Lect 2008; 57: 249-254.

92. Wesseling M, Meyer C, Corten K, Simon J-P, Desloovere K, Jonkers I. Does surgical approach or prosthesis type affect hip joint loading one year after surgery? Gait & posture 2016; 44: 74-82.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

93. Whatling GM, Dabke HV, Holt CA, Jones L, Madete J, Alderman PM, et al. Objective functional assessment of total hip arthroplasty following two common surgical approaches: the posterior and direct lateral approaches. Proceedings of the Institution of Mechanical Engineers. Part H, Journal of engineering in medicine, vol. 2222008:897-905.

94. Wimmer MA, Hildebrand M, Moisio KC, Foucher KC, Della Valle CJ, Berger RA, et al. Recovery after minimally invasive total hip arthroplasty: a gait study. Minerva Ortopedica E Traumatologica 2012; 63: 101-110.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

## Acknowledgements and Funding

This research was supported by the Australian Government Research Training Program Scholarship for Mr Jasvir S. Bahl and Mr Maximillian J Nelson. JBA is currently supported by a National Health & Medical Research Council Early Career Research Fellowship (ID: 1120560). DT is currently supported by a National Health & Medical Research Council Career Development Fellowship (ID: 1126229).

## Contributions

JSB & JA were responsible for the conception and design of the research, reviewing articles, analysing data, interpreting the results of the review, writing and drafting the manuscript, and approving the final version of the manuscript. MJN was responsible for performing the review, interpreting results of the research and revising the manuscript. MT was responsible for conception and design of the review, interpreting the results, and revision of the manuscript for important intellectual content. JK was responsible for interpreting the results of the review and revision of the article for important intellectual content. LBS and DT were responsible for conception and design of the review, interpreting the results of the review, revision of the article for important intellectual content. All authors read and approved the final version of the manuscript.

## Role of the funding source

None of the funding sources had input into the study design, analysis and interpretation of data; in the writing of the manuscript; and in the decision to submit the manuscript for publication.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

**Figure 1.** Flowchart of study selection process

**Figure 2.** A (left) illustrates the change in walking speed following THA compared to the pre-operative status. B (right) compares post-operative THA patients to healthy individuals. Studies listed as (Author) a, b, c represent different surgical approaches used and reported in the study.

**Figure 3.** A (left) illustrates the change in step length following THA compared to the pre-operative status. B (right) compares post-operative THA patients to healthy individuals. Studies listed as (Author) a, b, c represent different surgical approaches used and reported in the study.

**Figure 4.** A (top) illustrates the change in sagittal plane hip flexion/extension ROM following THA compared to the pre-operative status. B (bottom) compares post-operative THA patients to healthy individuals. Studies listed as (Author) a, b, c represent different surgical approaches used and reported in the study.

**Figure 5.** A (top) illustrates the change in coronal plane hip abduction/adduction ROM following THA compared to the pre-operative status. B (bottom) compares post-operative THA patients to healthy individuals. Studies listed as (Author) a, b, c represent different surgical approaches used and reported in the study.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

| Author (year) | Study Design | Study Analyses | | Sample size (n=) | | Mean age, SD (years) | | Mean BMI, SD (kg/m²) | | Surgical approach | Follow-up time point(s) | QI Score (of 26) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre vs post | Post vs control | Patients (THA) | Controls | Patients (THA) | Controls | Patients (THA) | Controls | | | |
| Agostini et al 2014 [27] | Case control | | ✓ | 20 | 20 | 66.1 ± 7.2 | 65.4 ± 5.1 | M = 26.1 ± 2.1;<br>F = 27.7 ± 5.0 | M = 24.4 ± 3;<br>F = 23.2 ± 2.5 | Posterolateral | 3 mo, 6 mo, 12 mo | 22 |
| Ajemian et al 2004 [35] | Case series | ✓ | | 11 | N/A | 62.6 ± 8.6 | N/A | NR | N/A | Not specified | Pre-op, 4 mo, 8 mo | 12 |
| Aminian et al 1999 [36] | Case series | ✓ | | 12 | N/A | 64.5 ± 8.7 | N/A | 27.8 ± 2 | N/A | Not specified | Not specified | 11 |
| Atallah et al 2014 [37] | Case control | | ✓ | 17 | 14 | 65.9 ± 6.5 | 39.7 ± 17 | NR | NR | Not specified | Not specified | 15 |
| Beaulieu et al 2010 [38] | Case control | | ✓ | 20 | 20 | 66.2 ± 6.7 | 63.5 ± 4.4 | 27.2 ± 5 | 24.9 ± 3.5 | Lateral | 6-15 mo | 19 |
| Behery and Foucher 2014 [39] | Case series | ✓ | | 125 | N/A | 61 ± 10 | N/A | 28.2 ± 5 | N/A | Not specified | Pre-op, 15 mo | 7 |
| Bennett et al 2008 [28] | Case control | | ✓ | 134 | 10 | 74.4 ± 2.2 | 64 ± 3.6 | NR | NR | Posterior | 9-10 mo | 18 |
| Bennett et al 2006 [40] | RCT | ✓ | ✓ | a: 8<br>b: 9 | 10 | a: 60.8 ± 5.8<br>b: 60.1 ± 6.2 | 64 ± 3.6 | a: NR<br>b: NR | NR | a: Posterior<br>b: Posterior (small incision) | Pre-op, 1.38 mo | 14 |
| Berman et al 1991 [41] | Prospective cohort | ✓ | ✓ | 21 | 91 | NR | NR | NR | NR | Anterolateral | Pre-op, 0-4 mo, 5-8 mo, 9-12 mo, 13-18 mo | 11 |
| Bhargava et al 2007 [42] | Case control | | ✓ | 20 | NR | 51.6 (SD NR) | NR | NR | NR | Posterior | 6-51 mo | 15 |
| Bianchi et al 2012 [43] | Case series | ✓ | | a: 19<br>b: 17<br>c: 19 | N/A | a: 64.4 ± 4<br>b: 65.9 ± 4<br>c: 65.2 ± 3.5 | N/A | a: 27.5 ± 3.7<br>b: 27.1 ± 3.7<br>c: 26.1 ± 4 | N/A | a: Posterolateral (28mm head)<br>b: Posterolateral (36mm head)<br>c: Posterolateral (≥42mm head) | Pre-op, 2 mo, 4 mo | 21 |
| Bouffard et al 2011 [44] | Case control | | ✓ | 12 | 11 | 50.8 ± 6.1 | 45.7 ± 8.2 | 26.7 ± 4.7 | 26.3 ± 3 | Posterior (large diameter head) | 12 mo | 21 |
| Casartelli et al 2013 [29] | Case control | | ✓ | 26 | 26 | 65 ±8 | | NR | | Posterior & anterior[≠] | 6 mo | 21 |
| Cichy et al 2008 [45] | Case series | ✓ | | 30 | N/A | 63.6 ± 8.9 | N/A | NR | N/A | Anterolateral | Pre-op, 1 mo | 17 |
| Colgan et al 2016 [24] | Prospective cohort | ✓ | ✓ | 10 | NR | 55.4 ± 7 | NR | 27.1 ± 2.3 | NR | Anterolateral | Pre-op, 8 weeks | 19 |
| da Cunha et al 2016 [46] | Case series | ✓ | | 93 | N/A | 59.7 ± 11.3 | N/A | 28.2 ± 4.7 | N/A | Lateral | Pre-op, 3 mo | 20 |
| Foucher 2016 [32] | Case series | ✓ | | 145 | N/A | 61 ± 10 | N/A | 28.5 ± 5 | N/A | Not specified | Pre-op, 12 mo | 17 |
| Foucher et al 2015 [9] | Case series | ✓ | | 145 | N/A | 61 ± 10 | N/A | 28 ± 5 | N/A | Not specified | Pre-op, 14 mo | 17 |
| Foucher et al 2007 [5] | Prospective cohort | ✓ | ✓ | 28 | 25 | 63.6 ± 7.1 | 57.6 ± 7.7 | NR | NR | Posterior & lateral[≠] | Pre-op, 14 mo | 17 |
| Foucher et al 2010 [47] | Case control | | ✓ | 26 | 24 | 60 ± 9 | 54 ± 6 | NR | NR | Not specified | 3 weeks, 12 mo | 15 |
| Foucher et al 2011 [48] | RCT | ✓ | ✓ | a: 13<br>b: 13 | 25 | a: 57 ± 8<br>b: 63 ± 9 | 54 ± 6 | a: 27 ± 3<br>b: 27 ± 3 | 28 ± 6 | a: Anterolateral<br>b: Two incision (anterior and | 3 weeks, 3 mo, 6 mo, 12 mo | 23 |

ACCEPTED MANUSCRIPT

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | buttock) | | |
| Holnapy et al 2013 [49] | Prospective cohort | ✓ | ✓ | a: 25<br>b: 22<br>c: 25 | 45 | a: M = 60.1 ± 2.4;<br>F = 59.9 ± 3.4<br>b: M = 61.3 ± 3.4;<br>F = 62.2 ± 2.4<br>c: M = 61.2 ± 2.9;<br>F = 60.8 ± 3.0 | M = 60.9 ± 3.2;<br>F = 60.4 ± 4.1 | a: M = 30.3 ± 3.4;<br>F = 30.1 ± 3.1<br>b: M = 30.7 ± 2.8;<br>F = 29.8 ± 3.3<br>c: M = 31.3 ± 3.4;<br>F = 28.9 ± 2.7 | M = 24.3 ± 2.8;<br>F = 25.3 ± 2.4 | a: Lateral<br>b: Anterolateral<br>c: Posterior | Pre-op, 3 mo, 6 mo | 21 |
| Horstmann et al 2013 [50] | Prospective cohort | ✓ | ✓ | 52 | 24 | 58 ± 9 | 54 ± 6.6 | NR | NR | Lateral | Pre-op, 6 mo | 19 |
| Husby et al 2009 [51] | Case series | ✓ | | 12 | N/A | 56 ± 8 | N/A | 28.2 ± 6.5 | N/A | Lateral | Pre-op, 1 week, 5 weeks | 24 |
| Isobe et al 1998 [52] | Case series | ✓ | | 31 | N/A | 59.5 ± 8.8 | N/A | NR | N/A | Not specified | Pre-op, 6 mo, 12 mo, 18 mo, 2 y, 3 y, 4 y, 5 y, 6 y | 15 |
| Jensen et al 2015 [53] | Prospective cohort | ✓ | ✓ | 19 | 20 | 55 ± 6 | 57 ± 7 | 28.4 ± 2.8 | 25.6 ± 2.9 | Posterolateral | Pre-op, 2 mo, 6 mo | 22 |
| Jensen et al 2014 [54] | Case series | ✓ | | 38 | N/A | 56 ± 5.6 | N/A | 27.8 ± 3.6 | N/A | Not specified | Pre-op, 2 mo, 6 mo | 11 |
| Judd et al 2015 [55] | Case series | ✓ | | 5 | N/A | 62.4 ± 7.3 | N/A | 31.84 ± 4.3 | N/A | Posterior | Pre-op, 8 wk | 19 |
| Kanzaki et al 2008 [56] | Case control | | ✓ | 9 | 11 | 46.3 ± 12.4 | 48.9 ± 8.2 | 20.6 ± 2.5 | 19.6 ± 1.7 | Anterolateral (Dall's) | 4 wk, 6 mo | 18 |
| Kiss et al 2012 [25] | Prospective cohort | ✓ | ✓ | a: 40<br>b: 40 | 40 | a: 71.3 ± 3.7<br>b: 70.1 ± 1.4 | 70.8 ± 3.1 | a: 29.9 ± 2.4<br>b: 29.8 ± 1.6 | 25.6 ± 3.8 | a: Lateral<br>b: Anterolateral | Pre-op, 3 mo, 6 mo, 12 mo | 23 |
| Klausmeier et al 2010 [57] | Prospective cohort | ✓ | ✓ | a: 11<br>b: 12 | 10 | a: 57 ± 7.3<br>b: 56.9 ± 3.3 | 59.9 ± 5.3 | a: 31.1 ± 4.1<br>b: 32 ± 5.1 | 26.3 ± 3.9 | a: Anterolateral<br>b: Anterior | Pre-op, 6 wk, 4 mo | 21 |
| Krych et al 2011 [58] | RCT | ✓ | | a: 8<br>b: 11 | N/A | a: 64.5 ± 13.4<br>b: 65.64 ± 12.1 | N/A | a: 29.38 ± 6.5<br>b: 28.45 ± 3.4 | N/A | a: Posterior (mini-incision)<br>b: Two incision (anterior and buttock) | Pre-op, 2 mo, 12 mo | 21 |
| Krych et al 2010 [59] | Case series | ✓ | | Total 21<br>a: 10<br>b 11 | N/A | Total 63 ± 13<br>a: NR<br>b: NR | N/A | Total 30 ± 6<br>a: NR<br>b: NR | N/A | a: Posterior (mini-incision)<br>b: Two incision (anterior and buttock) | Pre-op, 6 wk | 15 |
| Lavigne et al 2010 [60] | Randomised double-blind | ✓ | ✓ | 24 | 14 | 49.8 ± 7.3 | 44.4 ± 6.3 | 27.8 ± 3.9 | 25.8 ± 2.9 | Posterior | Pre-op 3 mo, 6 mo, 12 mo | 24 |
| Lenaerts et al 2009 [61] | Case series | ✓ | | 20 | N/A | 63 ± 9.8 | N/A | 27.4 ± 3.9 | N/A | Lateral | Pre-op, 6 wk | 15 |
| Li et al 2015 [62] | Case control | | ✓ | 15 | 15 | 64 ± 2.7 | 58 ± 1.5 | 30.7 ± 1.5 | 24.5 ± 0.7 | Not specified | > 12 mo | 14 |
| Li et al 2014 [63] | Case control | | ✓ | 15 | 38 | 64.27 ± 2.8 | 44.97 ± 2 | 30.74 ± 1.5 | 24.72 ± 0.4 | Anterior | > 12 mo | 14 |
| Loizeau et al 1995 [64] | Case control | | ✓ | 4 | 4 | 67.3 ± 8 | 58.9 ± 8.9 | NR | NR | Not specified | 3.8 y | 16 |
| Lugade et al 2008 [65] | Prospective cohort | ✓ | ✓ | 20 | 10 | 57 ± 5.2 | 59.9 ± 5.3 | 31.9 ± 4.3 | 26.3 ± 3.9 | Anterior & lateral≠ | Pre-op, 6 wk, 4 months | 22 |
| Lugade et al 2010 [66] | Prospective cohort | ✓ | ✓ | a: 12<br>b:11 | 10 | a: 56.9 ± 3.4<br>b: 57 ± 7.3 | 59.9 ± 5.3 | a: 32 ± 5.1<br>b: 31.1 ± 4.1 | 26.3 ± 3.9 | a: Anterior<br>b: Anterolateral | Pre-op, 6 wk, 4 mo | 22 |
| Madsen et al 2004 [67] | Case control | | ✓ | a: 10<br>b: 10 | 9 | a: 60.7 ± 8.4<br>b: 63.6 ± 8 | 54 ± 9.5 | a: NR<br>b: NR | NR | a: Anterolateral<br>b: Posterolateral | 6 mo | 20 |

ACCEPTED MANUSCRIPT

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maffiuletti et al 2009 [30] | Case control | | ✓ | a: 17<br>b: 17 | 17 | a: 69 ± 5<br>b: 68 ± 6 | 69 ± 4 | a: 27.2 ± 4.2<br>b: 25.6 ± 3.3 | 25.5 ± 2.7 | a: Posterior<br>b: Anterior | 6 mo | 21 |
| Mantovani et al 2012 [68] | Case control | | ✓ | a: 20<br>b: 20 | 20 | a: 60.5 ± 6<br>b: 66.2 ± 6.7 | 63.5 ± 4.4 | a: 28.5 ± 4.9<br>b: 27.2 ± 5 | 24.9 ± 3.5 | a: Anterior<br>b: Lateral | 11 mo<br>10 mo | 15 |
| Martinez-Ramirez et al 2014 [69] | Case series | ✓ | | 19 | N/A | 62 ± 9 | N/A | NR | N/A | Not specified | Pre-op, 6-8 mo | 17 |
| Mayr et al 2009 [34] | Prospective cohort | ✓ | ✓ | a: 16<br>b: 17 | 20 | a: 66 ± 10<br>b: 68 ± 10 | 27.9 ± 3.3 | a: 27 ± 3.8<br>b: 29 ± 3.6 | NR | a: Anterior<br>b: Anterolateral | Pre-op, 6 weeks, 3 mo | 22 |
| McCrory et al 2001 [70] | Case control | | ✓ | 27 | 35 | 59.7 ± 13.8 | 27.5 ± 5.7 | NR | NR | Not specified | 10.5 mo | 16 |
| Meneghini et al 2008 [71] | Case series | ✓ | | a: 8<br>b: 8<br>c: 7 | N/A | a: 54 ± 9<br>b: 54 ± 9<br>c: 54 ± 9 | N/A | a: 26 ± 2.3<br>b: 26 ± 2.3<br>c: 26 ± 2.3 | N/A | a: Two incision (anterior and buttock)<br>b: Posterior (mini incision)<br>c: Anterolateral (mini incision) | Pre-op, 6 wk | 20 |
| Miki et al 2004 [72] | Case series | ✓ | | 17 | N/A | 52.6 (SD NR) | N/A | NR | N/A | Posterior | Pre-op, 1 mo, 3 mo, 6 mo, 12 mo | 20 |
| Muller et al 2012 [73] | Case series | ✓ | | a: 15<br>b: 15 | N/A | a: 64.3 ± 7<br>b: 66.2 ± 8 | N/A | a: 26.9 ± 3.3<br>b: 27 ± 3.1 | N/A | a: Anterolateral<br>b: Direct lateral | Pre-op, 3 mo | 22 |
| Nankaku et al 2012 [74] | Case control | | ✓ | 18 | 18 | 47.7 ± 10 | 47.4 ± 15.3 | 20.4 ± 2.1 | 20.8 ± 1.9 | Direct lateral (Dall's) | 4 weeks | 18 |
| Nankaku et al 2007 [75] | Case control | | ✓ | 15 | 14 | 47 ± 10.2 | 46 ± 13.2 | 20.3 ± 2.2 | 20.7 ± 1.9 | Anterolateral (Dall's) | 4 weeks | 20 |
| Nantel et al 2009 [76] | Case control | | ✓ | 10 | 10 | 49 ± 7.5 | 48.6 ± 6 | 29.9 ± 6.6 | 26.4 v 3.4 | Posterior | 6 weeks | 21 |
| Perron et al 2000 [12] | Case control | | ✓ | 18 | 15 | 65.6 ± 6 | 65.5 ± 6.5 | NR | NR | Posterior & anterolateral[≠] | 10.7 mo | 17 |
| Queen et al 2011 [10] | Case series | ✓ | | a: 8<br>b: 12<br>c: 15 | N/A | a: 58 ± 7<br>b: 55.3 ± 8.2<br>c: 55.4 ± 10.9 | N/A | a: NR<br>b: NR<br>c: NR | N/A | a: Lateral<br>b: Posterior<br>c: Anterolateral | Pre-op, 6 weeks | 20 |
| Queen et al 2013 [77] | Case series | ✓ | | a: 10<br>b: 10<br>c: 10 | N/A | a: 60 ± 6.5<br>b: 57 ± 6.2<br>c: 57.6 ± 11.2 | N/A | a: NR<br>b: NR<br>c: NR | N/A | a: Lateral<br>b: Posterior<br>c: Anterolateral | Pre-op, 6 weeks, 12 mo | 19 |
| Rathod et al 2014 [78] | Case series | ✓ | | a: 11<br>b: 11 | N/A | a: 58 ± 6.7<br>b: 61.8 ± 9.1 | N/A | a: 25.9 ± 2.2<br>b: 25.43 ± 3 | N/A | a: Anterior<br>b: Posterior | Pre-op, 6 mo, 12 mo | 24 |
| Reininga et al 2013 [79] | Prospective cohort | ✓ | ✓ | 40 | 30 | 60.5 ± 9.5 | 65.8 ± 6 | 26.2 ± 3.5 | 23.9 ± 3.2 | Posterior | Pre-op, 6 weeks, 3 mo, 6 mo | 23 |
| Rosenberg 1982 [80] | Case control | | ✓ | 10 | 10 | 66.4 ± 6.9 | 64.9 ± 4.8 | NR | NR | Anterolateral | > 12mo | 15 |
| Rosler and Perka 2000 [81] | Prospective cohort | ✓ | ✓ | 26 | 10 | 64.6 ± 7.7 | 42.1 ± 13.5 | NR | NR | Lateral | Pre-op, 14.4 wk, 27.8 wk | 13 |
| Shrader et al 2009 [82] | Prospective cohort | ✓ | ✓ | 7 | 7 | 51.9 ± 10.1 | 50.4 ± 8.2 | NR | NR | Posterolateral | Pre-op, 3 mo | 20 |
| Sicard-Rosenbaum et al 2002 [11] | Case control | | ✓ | 15 | 30 | 59.9 ± 14.9 | 60.2 ± 15 | NR | NR | Not specified | 23.6 mo | 14 |
| Stansfield and Nicol 2002 [83] | Case control | | ✓ | 5 | M = 5;<br>F = 6 | 52.6 ± 6.6 | M = 49.4 ± 5;<br>F = 49.7 ± 5.2 | NR | M = NR;<br>F = NR | Not specified | 18.6 mo | 11 |

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Talis et al 2008 [84] | Case control | | ✓ | 27 | 27 | 56 ± 10 | 55 ± 9 | NR | NR | Not specified | 19 mo | 17 |
| Tanaka et al 2010 [85] | Prospective cohort | ✓ | ✓ | 43 | 26 | 59.7 ± 7.9 | 61.3 ± 11.4 | NR | NR | Posterolateral | Pre-op, 2 mo, 6 mo, 12 mo | 20 |
| Tateuchi et al 2011 [31] | Case control | | ✓ | 12 | 12 | 63.2 ± 7.2 | 63.4 ± 5.1 | 22.5 ± 3.3 | 21.6 ± 2.1 | Not specified | > 6 mo | 18 |
| van den Akker-Scheek et al 2007 [86] | Prospective cohort | ✓ | ✓ | 63 | 19 | 62 ± 12.6 | 61.7 ± 9.4 | 26.4 ± 3.3 | 24.9 ± 2.3 | Not specified | Pre-op, 6 weeks, 6 mo | 19 |
| Varin et al 2013 [87] | Case control | | ✓ | a: 20<br>b: 20 | 20 | a: 66.2 ± 6.7<br>b: 60.5 ± 6 | 63.5 ± 9.4 | a: 27.2 ± 5<br>b: 28.5 ± 4.9 | 24.9 ± 3.5 | a: Lateral<br>b: Anterior | 10.6 mo<br>9.6 mo | 20 |
| Vogt et al 2004 [88] | Case control | | ✓ | 14 | 10 | 63 ± 4 | 61± 6 | NR | NR | Posterolateral | 6 weeks | 13 |
| Vogt et al 2003 [89] | Case control | | ✓ | 12 | 10 | 61.5 ± 6.7 | 59.5 ± 6.1 | NR | NR | Not specified | 6 weeks | 16 |
| Waldman and Foucher 2012 [90] | Case series | ✓ | | 132 | N/A | 60.5 ± 10 | N/A | 28.5 ± 4 | N/A | Not specified | Pre-op, 12 mo | 8 |
| Ward et al 2008 [91] | Case series | ✓ | | a: 11<br>b: 10<br>c: 18<br>d: 30 | N/A | a: 55 ± 2<br>b: 64 ± 2<br>c: 61 ± 2<br>d: 64 ± 1 | N/A | a: 28.9 ± 1.2<br>b: 27.8 ± 1.1<br>c: 29.8 ± 1<br>d: 26.1 ± 0.5 | N/A | a: Anterolateral (mini incision)<br>b: Anterolateral (Judet mini incision)<br>c: Posterior<br>d: Posterior (mini incision) | Pre-op, 6 weeks, 6 mo | 14 |
| Wesseling et al 2016 [92] | Case control | | ✓ | 12 | 18 | 47.75 ± 13.2 | 53 ± 5 | 25.52 ± 3 | 23.67 ± 3 | Anterior | 12 mo | 17 |
| Whatling et al 2008 [93] | Prospective cohort | ✓ | ✓ | a: 14<br>b: 13 | 16 | a: 64.21± 10.9<br>b: 60.46 ± 11.5 | 46.25 ± 7.4 | a: NR<br>b: NR | NR | a: Direct lateral<br>b: Posterior | Not stated | 10 |
| Wimmer et al 2012 [94] | Prospective cohort | ✓ | ✓ | a: 10<br>b: 12<br>c: 7 | 23 | a: 59 ± 7.3<br>b: 55.7 ± 9.9<br>c: 57 ± 11.8 | 53.8 ± 6.5 | a: 26.7 ± 2.2<br>b: 28.9 ± 3.8<br>c: 30.7 ± 6.6 | 26.1 ± 4.9 | a: Two incision (anterior and buttock)<br>b: Anterolateral (mini incision)<br>c: Posterolateral (mini incision) | 6 weeks, 3 mo | 16 |

≠ Surgical approaches combined; *Missing gait data where authors were contacted; SD, standard deviation; RCT, randomised controlled trial; NR, not reported; N/A, not applicable; mo, months; wk, week; y, year.

ACCEPTED MANUSCRIPT

**Table 1.** Summary of findings for gait parameters across each time point. Change from pre-operative to post-operative and comparison of post-operative THA patients to healthy individuals

| **Pre-operative vs post-operative** | | | | | **Post-operative THA patients vs healthy individuals** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Follow-up time points and variables** | **Study groups (n=)** | **$I^2$, %** | **SMD (95% CI)** | **Strength of evidence*** | **Follow-up time points and variables** | **Study groups (n=)** | **$I^2$, %** | **SMD (95% CI)** | **Strength of evidence*** |
| **6 weeks** | | | | | **6 weeks** | | | | |
| Velocity | 20 | 70 | 0.32 (0.14 – 0.50) | Moderate | Velocity | 13 | 69 | -1.81 (-2.22 to -1.40) | Moderate |
| Single limb support time | 5 | 36 | 0.44 (0.19 – 0.69) | Moderate | Single limb support time | 6 | 79 | -0.72 (-1.38 to -0.05) | Moderate |
| Double limb support time | 3 | 50 | -0.03 (-0.46 to 0.40) | Moderate | Double limb support time | 3 | 91 | 2.22 (0.26 – 4.19) | Moderate |
| Stride length | 11 | 87 | 0.40 (0.19 – 0.61) | Moderate | Stride length | 8 | 61 | -1.90 (-2.43 to -1.37) | Moderate |
| Stride time | 3 | 70 | 0.04 (-0.13 to 0.20) | Moderate | Step width | 5 | 0 | 1.33 (0.91 – 1.75) | Strong |
| Step width | 5 | 66 | 0.05 (-0.25 to 0.35) | Strong | Step length | 2 | 49 | -1.36 (-1.90 to -0.83) | Moderate |
| Step length | 10 | 75 | 0.41 (0.23 – 0.59) | Moderate | Hip flexion/extension ROM | 4 | 0 | -2.59 (-3.11 to -2.06) | Moderate |
| Hip flexion/extension ROM | 4 | 88 | 0.49 (-0.29 to 1.27) | Moderate | Hip abduction/adduction ROM | 4 | 44 | -1.76 (-2.36 to -1.15) | Moderate |
| Hip abduction/adduction ROM | 4 | 39 | 0.33 (-0.19 to 0.86) | Strong | Hip internal/external ROM | 4 | 13 | 0.18 (-0.23 to 0.59) | Moderate |
| Hip internal/external ROM | 4 | 9 | 0.36 (0.05 – 0.67) | Strong | | | | | |
| **3 months** | | | | | **3 months** | | | | |
| Velocity | 17 | 63 | 0.78 (0.57 – 0.99) | Moderate | Velocity | 10 | 82 | -1.22 (-1.83 to -0.61) | Moderate |
| Single limb support time | 5 | 28 | 0.59 (0.35 – 0.82) | Strong | Single limb support time | 4 | 78 | -0.73 (-1.59 to 0.12) | Moderate |
| Stride length | 7 | 51 | 0.63 (0.38 – 0.88) | Moderate | Double limb support time | 5 | 97 | -0.28 (-2.05 to 1.58) | Moderate |
| Stride time | 3 | 60 | -0.38 (-0.68 to -0.07) | Moderate | Stride length | 6 | 80 | -1.60 (-2.45 to -0.74) | Moderate |
| Step width | 8 | 90 | 0.02 (-0.63 to 0.66) | Moderate | Step width | 8 | 94 | 1.90 (0.60 – 3.20) | Moderate |
| Step length | 7 | 31 | 0.52 (0.33 – 0.71) | Strong | Step length | 3 | 0 | -0.88 (-0.68 to -0.01) | Moderate |
| Hip flexion/extension ROM | 4 | 80 | 1.07 (0.31 – 1.84) | Moderate | Swing time | 3 | 0 | -0.39 (-0.67 to -0.11) | Strong |
| Hip abduction/adduction ROM | 5 | 95 | 1.03 (0.24 – 1.82) | Moderate | Hip flexion/extension ROM | 5 | 56 | -1.88 (-2.47 to -1.28) | Strong |
| Hip internal/external ROM | 4 | 89 | 0.50 (0.01 – 1.00) | Moderate | Hip abduction/adduction ROM | 4 | 0 | -1.41 (-1.83 to -0.99) | Strong |
| Peak hip flexion angle | 3 | 86 | 0.16 (-0.47 to 0.78) | Moderate | Hip internal/external ROM | 4 | 79 | 0.26 (-0.60 to 1.11) | Moderate |
| Peak hip abduction angle | 2 | 0 | -0.39 (-0.62 to -0.16) | Moderate | Pelvis obliquity ROM | 3 | 99 | -0.20 (-3.31 to 2.90) | Moderate |
| | | | | | Peak pelvis obliquity angle | 4 | 96 | -0.24 (-1.83 to 1.34) | Moderate |
| | | | | | Minimum pelvis obliquity angle | 4 | 96 | -0.41 (-1.96 to 1.13) | Moderate |
| | | | | | Peak hip abduction moment | 4 | 21 | 0.02 (-0.44 to 0.49) | Moderate |
| **6 months** | | | | | **6 months** | | | | |
| Velocity | 9 | 32 | 1.01 (0.81 – 1.21) | Strong | Velocity | 8 | 64 | -0.69 (-1.10 to -0.29) | Moderate |

ACCEPTED MANUSCRIPT

| | | | | |
|---|---|---|---|---|
| Step length | 6 | 75 | 0.90 (0.50 – 1.31) | Moderate |
| Cadence | 6 | 96 | -0.08 (-1.05 to 0.89) | Moderate |

**Pre-operative vs post-operative**

| Follow-up time points and variables | Study groups (n=) | $I^2$, % | SMD (95% CI) | Strength of evidence* |
|---|---|---|---|---|
| Stance phase | 3 | 34 | -0.14 (-0.42 to 0.13) | Limited |
| Pelvic obliquity ROM | 4 | 98 | -0.81 (-2.60 to 0.99) | Moderate |
| **12 months** | | | | |
| Velocity | 11 | 78 | 1.28 (1.01 – 1.56) | Moderate |
| Hip abduction/adduction ROM | 4 | 39 | 0.33 (-0.19 to 0.86) | Strong |
| Hip internal/external ROM | 4 | 9 | 0.36 (0.05 – 0.67) | Strong |

| | | | | |
|---|---|---|---|---|
| Single limb support time | 5 | 82 | -0.33 (-1.08 to 0.42) | Moderate |
| Double limb support time | 7 | 88 | 0.18 (-0.51 to 0.88) | Moderate |

**Post-operative THA patients vs healthy individuals**

| Follow-up time points and variables | Study groups (n=) | $I^2$, % | SMD (95% CI) | Strength of evidence* |
|---|---|---|---|---|
| Stride length | 7 | 0 | -0.78 (-1.06 to -0.49) | Strong |
| Step length | 4 | 51 | -0.35 (-0.68 to -0.01) | Strong |
| Swing time | 5 | 75 | 0.36 (-0.14 to 0.86) | Moderate |
| Hip flexion/extension ROM | 3 | 0 | -1.33 (-1.83 to -0.82) | Strong |
| Pelvis obliquity ROM | 5 | 95 | 0.28 (-1.02 to 1.57) | Moderate |
| **12 months** | | | | |
| Velocity | 7 | 77 | -0.59 (-1.08 to -0.11) | Moderate |
| Single limb support time | 2 | 0 | -0.82 (-1.23 to -0.41) | Moderate |
| Double limb support time | 3 | 59 | -0.38 (-0.83 to 0.08) | Moderate |
| Stride length | 3 | 0 | -1.27 (-1.63 to -0.91) | Moderate |
| Step length | 3 | 90 | -0.54 (-1.46 to 0.38) | Moderate |
| Hip flexion/extension ROM | 3 | 65 | -1.16 (-1.83 to -0.49) | Strong |
| Peak hip extension angle | 4 | 97 | 0.11 (-1.68 to 1.91) | Moderate |
| Pelvis obliquity ROM | 4 | 78 | 0.09 (-0.47 to 0.65) | Moderate |
| Pelvis flexion/extension ROM | 5 | 73 | 0.48 (0.00 – 0.96) | Moderate |
| **24 months** | | | | |
| Velocity | 2 | 0 | -0.57 (-0.98 to -0.15) | Limited |

* Strength of evidence was determined as per Van Tulder et al 2003 [25]

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

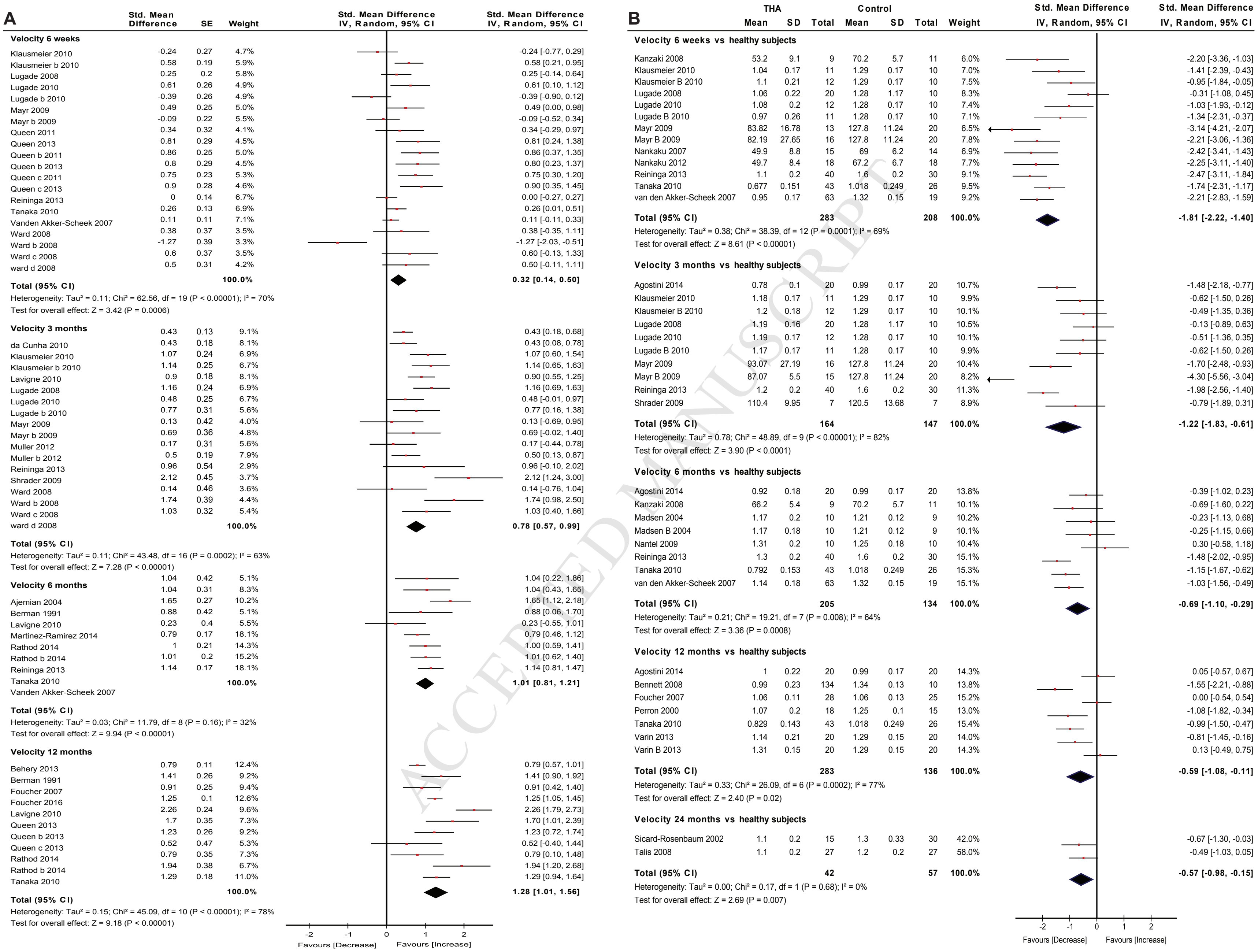
**Table 1.** Meta Regression Analysis of Factors Potentially Related to Heterogeneity

| | Velocity 6 weeks | | Velocity 3 months | | Velocity 12 months | | Step length 6 weeks | | Stride length 6 weeks | |
|---|---|---|---|---|---|---|---|---|---|---|
| | β (95% CI) | *P* Value | β (95% CI) | *P* Value | β (95% CI) | *P* Value | β (95% CI) | *P* Value | β (95% CI) | *P* Value |
| Age | -0.25<br>(-0.77 to 0.27) | .324 | -.052<br>(-.102 to -.001) | **.046** | -.094<br>(-.185 to -.003) | **.045** | -.029<br>(-.107 to .048) | .406 | -.021<br>(-.086 to .044) | .484 |
| BMI | -.002<br>(-.106 to .102) | .968 | .055<br>(-.093 to .204) | .437 | .011<br>(-.867 to .889) | .970 | .255<br>(-1.244 to 1.755) | .275 | -.012<br>(-.433 to .409) | .932 |
| Sample size | -.008<br>(-0.20 to .005) | .217 | -.005<br>(-.019 to .010) | .508 | -.002<br>(-.010 to .006) | .583 | -.011<br>(-.020 to -.001) | **.033** | -.034<br>(-.112 to .045) | .354 |
| Surgical Approach* | .195<br>(-.315 to .705) | .431 | .224<br>(-.532 to .981) | .537 | .725<br>(-.477 to 1.927) | .206 | - | - | .354<br>(-.290 to .998) | .245 |
| % females | .003<br>(-.007 to .014) | .497 | -.005<br>(-.017 to .007) | .386 | -.006<br>(-.037 to .025) | .645 | -.016<br>(-.040 to .008) | .141 | .011<br>(-.012 to .034) | .271 |
| Risk of bias | -.047<br>(-.105 to .011) | .107 | -.062<br>(-.131 to .007) | .073 | .051<br>(-.042 to .144) | .246 | -.041<br>(-.132 to .050) | .326 | -.095<br>(-.254 to .064) | .210 |

*Comparison of the gluteal muscle sparing (anterior) approach to the more conventional posterior and lateral surgical approaches.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT



**A**

| | Std. Mean Difference | SE | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|
| **Velocity 6 weeks** | | | | |
| Klausmeier 2010 | -0.24 | 0.27 | 4.7% | -0.24 [-0.77, 0.29] |
| Klausmeier b 2010 | 0.58 | 0.19 | 5.9% | 0.58 [0.21, 0.95] |
| Lugade 2008 | 0.25 | 0.2 | 5.8% | 0.25 [-0.14, 0.64] |
| Lugade 2010 | 0.61 | 0.26 | 4.9% | 0.61 [0.10, 1.12] |
| Lugade b 2010 | -0.39 | 0.26 | 4.9% | -0.39 [-0.90, 0.12] |
| Mayr 2009 | 0.49 | 0.25 | 5.0% | 0.49 [0.00, 0.98] |
| Mayr b 2009 | -0.09 | 0.22 | 5.5% | -0.09 [-0.52, 0.34] |
| Queen 2011 | 0.34 | 0.32 | 4.1% | 0.34 [-0.29, 0.97] |
| Queen 2013 | 0.81 | 0.29 | 4.5% | 0.81 [0.24, 1.38] |
| Queen b 2011 | 0.86 | 0.25 | 5.0% | 0.86 [0.37, 1.35] |
| Queen b 2013 | 0.8 | 0.29 | 4.5% | 0.80 [0.23, 1.37] |
| Queen c 2011 | 0.75 | 0.23 | 5.3% | 0.75 [0.30, 1.20] |
| Queen c 2013 | 0.9 | 0.28 | 4.6% | 0.90 [0.35, 1.45] |
| Reininga 2013 | 0 | 0.14 | 6.7% | 0.00 [-0.27, 0.27] |
| Tanaka 2010 | 0.26 | 0.13 | 6.9% | 0.26 [0.01, 0.51] |
| Vanden Akker-Scheek 2007 | 0.11 | 0.11 | 7.1% | 0.11 [-0.11, 0.33] |
| Ward 2008 | 0.38 | 0.37 | 3.5% | 0.38 [-0.35, 1.11] |
| Ward b 2008 | -1.27 | 0.39 | 3.3% | -1.27 [-2.03, -0.51] |
| Ward c 2008 | 0.6 | 0.37 | 3.5% | 0.60 [-0.13, 1.33] |
| ward d 2008 | 0.5 | 0.31 | 4.2% | 0.50 [-0.11, 1.11] |
| **Total (95% CI)** | | | **100.0%** | **0.32 [0.14, 0.50]** |
| Heterogeneity: Tau² = 0.11; Chi² = 62.56, df = 19 (P < 0.00001); I² = 70% | | | | |
| Test for overall effect: Z = 3.42 (P = 0.0006) | | | | |
| **Velocity 3 months** | | | | |
| da Cunha 2010 | 0.43 | 0.13 | 9.1% | 0.43 [0.18, 0.68] |
| Klausmeier 2010 | 0.43 | 0.18 | 8.1% | 0.43 [0.08, 0.78] |
| Klausmeier b 2010 | 1.07 | 0.24 | 6.9% | 1.07 [0.60, 1.54] |
| Lavigne 2010 | 1.14 | 0.25 | 6.7% | 1.14 [0.65, 1.63] |
| Lugade 2008 | 0.9 | 0.18 | 8.1% | 0.90 [0.55, 1.25] |
| Lugade 2010 | 1.16 | 0.24 | 6.9% | 1.16 [0.69, 1.63] |
| Lugade b 2010 | 0.48 | 0.25 | 6.7% | 0.48 [-0.01, 0.97] |
| Mayr 2009 | 0.77 | 0.31 | 5.6% | 0.77 [0.16, 1.38] |
| Mayr b 2009 | 0.13 | 0.42 | 4.0% | 0.13 [-0.69, 0.95] |
| Muller 2012 | 0.69 | 0.36 | 4.8% | 0.69 [-0.02, 1.40] |
| Muller b 2012 | 0.17 | 0.31 | 5.6% | 0.17 [-0.44, 0.78] |
| Reininga 2013 | 0.5 | 0.19 | 7.9% | 0.50 [0.13, 0.87] |
| Shrader 2009 | 0.96 | 0.54 | 2.9% | 0.96 [-0.10, 2.02] |
| Ward 2008 | 2.12 | 0.45 | 3.7% | 2.12 [1.24, 3.00] |
| Ward b 2008 | 0.14 | 0.46 | 3.6% | 0.14 [-0.76, 1.04] |
| Ward c 2008 | 1.74 | 0.39 | 4.4% | 1.74 [0.98, 2.50] |
| ward d 2008 | 1.03 | 0.32 | 5.4% | 1.03 [0.40, 1.66] |
| **Total (95% CI)** | | | **100.0%** | **0.78 [0.57, 0.99]** |
| Heterogeneity: Tau² = 0.11; Chi² = 43.48, df = 16 (P = 0.0002); I² = 63% | | | | |
| Test for overall effect: Z = 7.28 (P < 0.00001) | | | | |
| **Velocity 6 months** | | | | |
| Ajemian 2004 | 1.04 | 0.42 | 5.1% | 1.04 [0.22, 1.86] |
| Berman 1991 | 1.04 | 0.31 | 8.3% | 1.04 [0.43, 1.65] |
| Lavigne 2010 | 1.65 | 0.27 | 10.2% | 1.65 [1.12, 2.18] |
| Martinez-Ramirez 2014 | 0.88 | 0.42 | 5.1% | 0.88 [0.06, 1.70] |
| Rathod 2014 | 0.23 | 0.4 | 5.5% | 0.23 [-0.55, 1.01] |
| Rathod b 2014 | 0.79 | 0.17 | 18.1% | 0.79 [0.46, 1.12] |
| Reininga 2013 | 1 | 0.21 | 14.3% | 1.00 [0.59, 1.41] |
| Tanaka 2010 | 1.01 | 0.2 | 15.2% | 1.01 [0.62, 1.40] |
| Vanden Akker-Scheek 2007 | 1.14 | 0.17 | 18.1% | 1.14 [0.81, 1.47] |
| **Total (95% CI)** | | | **100.0%** | **1.01 [0.81, 1.21]** |
| Heterogeneity: Tau² = 0.03; Chi² = 11.79, df = 8 (P = 0.16); I² = 32% | | | | |
| Test for overall effect: Z = 9.94 (P < 0.00001) | | | | |
| **Velocity 12 months** | | | | |
| Behery 2013 | 0.79 | 0.11 | 12.4% | 0.79 [0.57, 1.01] |
| Berman 1991 | 1.41 | 0.26 | 9.2% | 1.41 [0.90, 1.92] |
| Foucher 2007 | 0.91 | 0.25 | 9.4% | 0.91 [0.42, 1.40] |
| Foucher 2016 | 1.25 | 0.1 | 12.6% | 1.25 [1.05, 1.45] |
| Lavigne 2010 | 2.26 | 0.24 | 9.6% | 2.26 [1.79, 2.73] |
| Queen 2013 | 1.7 | 0.35 | 7.3% | 1.70 [1.01, 2.39] |
| Queen b 2013 | 1.23 | 0.26 | 9.2% | 1.23 [0.72, 1.74] |
| Queen c 2013 | 0.52 | 0.47 | 5.3% | 0.52 [-0.40, 1.44] |
| Rathod 2014 | 0.79 | 0.35 | 7.3% | 0.79 [0.10, 1.48] |
| Rathod b 2014 | 1.94 | 0.38 | 6.7% | 1.94 [1.20, 2.68] |
| Tanaka 2010 | 1.29 | 0.18 | 11.0% | 1.29 [0.94, 1.64] |
| **Total (95% CI)** | | | **100.0%** | **1.28 [1.01, 1.56]** |
| Heterogeneity: Tau² = 0.15; Chi² = 45.09, df = 10 (P < 0.00001); I² = 78% | | | | |
| Test for overall effect: Z = 9.18 (P < 0.00001) | | | | |

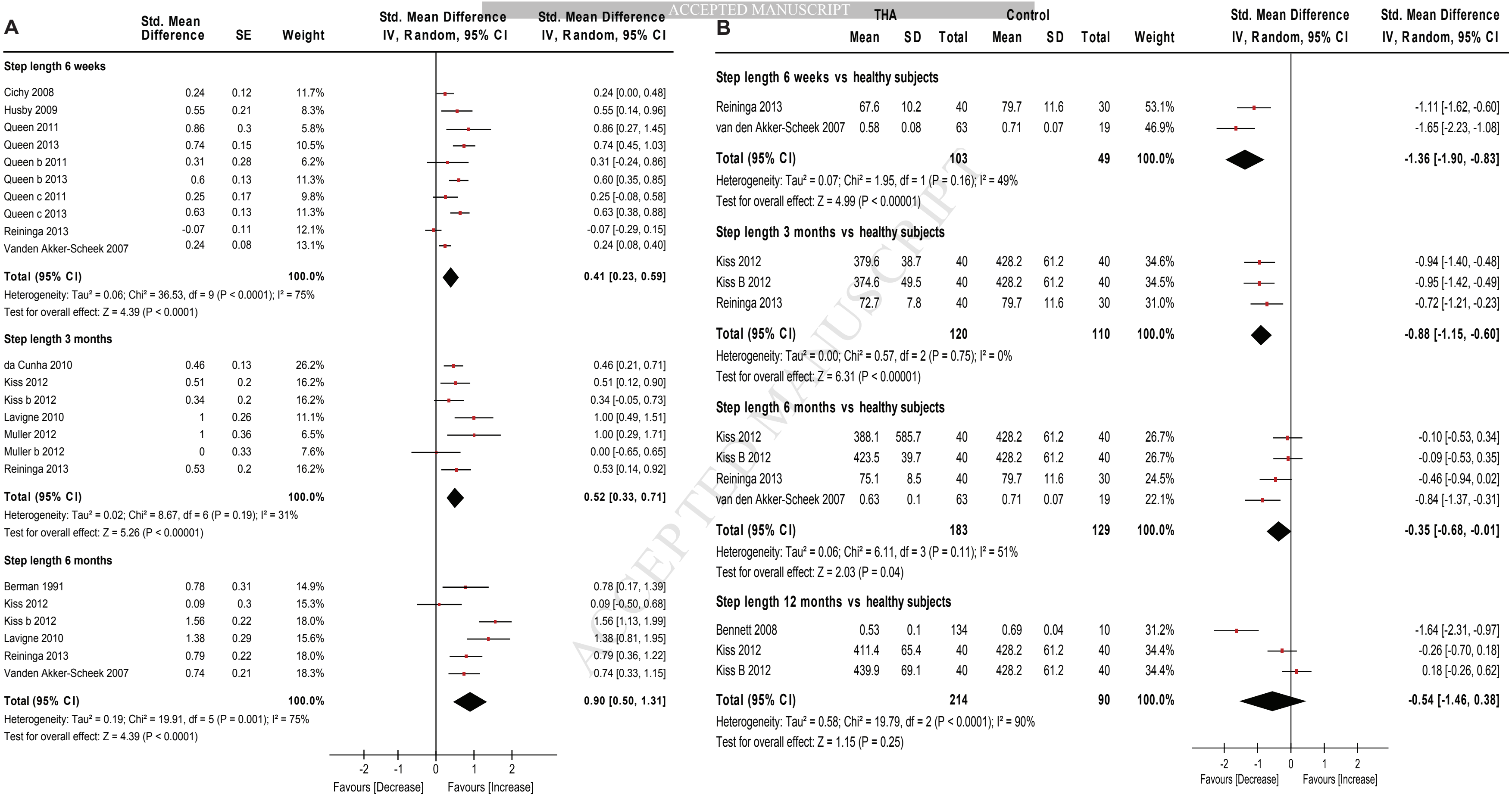
**B**

| | THA | | | Control | | | | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Total | Mean | SD | Total | Weight | |
| **Velocity 6 weeks vs healthy subjects** | | | | | | | | |
| Kanzaki 2008 | 53.2 | 9.1 | 9 | 70.2 | 5.7 | 11 | 6.0% | -2.20 [-3.36, -1.03] |
| Klausmeier 2010 | 1.04 | 0.17 | 11 | 1.29 | 0.17 | 10 | 7.0% | -1.41 [-2.39, -0.43] |
| Klausmeier B 2010 | 1.1 | 0.21 | 12 | 1.29 | 0.17 | 10 | 7.5% | -0.95 [-1.84, -0.05] |
| Lugade 2008 | 1.06 | 0.22 | 20 | 1.28 | 1.17 | 10 | 8.3% | -0.31 [-1.08, 0.45] |
| Lugade 2010 | 1.08 | 0.2 | 12 | 1.28 | 0.17 | 10 | 7.4% | -1.03 [-1.93, -0.12] |
| Lugade B 2010 | 0.97 | 0.26 | 11 | 1.28 | 0.17 | 10 | 7.1% | -1.34 [-2.31, -0.37] |
| Mayr 2009 | 83.82 | 16.78 | 13 | 127.8 | 11.24 | 20 | 6.5% | -3.14 [-4.21, -2.07] |
| Mayr B 2009 | 82.19 | 27.65 | 16 | 127.8 | 11.24 | 20 | 7.8% | -2.21 [-3.06, -1.36] |
| Nankaku 2007 | 49.9 | 8.8 | 15 | 69 | 6.2 | 14 | 6.9% | -2.42 [-3.41, -1.43] |
| Nankaku 2012 | 49.7 | 8.4 | 18 | 67.2 | 6.7 | 18 | 7.7% | -2.25 [-3.11, -1.40] |
| Reininga 2013 | 1.1 | 0.2 | 40 | 1.6 | 0.2 | 30 | 9.1% | -2.47 [-3.11, -1.84] |
| Tanaka 2010 | 0.677 | 0.151 | 43 | 1.018 | 0.249 | 26 | 9.5% | -1.74 [-2.31, -1.17] |
| van den Akker-Scheek 2007 | 0.95 | 0.17 | 63 | 1.32 | 0.15 | 19 | 9.2% | -2.21 [-2.83, -1.59] |
| **Total (95% CI)** | | | **283** | | | **208** | **100.0%** | **-1.81 [-2.22, -1.40]** |
| Heterogeneity: Tau² = 0.38; Chi² = 38.39, df = 12 (P = 0.0001); I² = 69% | | | | | | | | |
| Test for overall effect: Z = 8.61 (P < 0.00001) | | | | | | | | |
| **Velocity 3 months vs healthy subjects** | | | | | | | | |
| Agostini 2014 | 0.78 | 0.1 | 20 | 0.99 | 0.17 | 20 | 10.7% | -1.48 [-2.18, -0.77] |
| Klausmeier 2010 | 1.18 | 0.17 | 11 | 1.29 | 0.17 | 10 | 9.9% | -0.62 [-1.50, 0.26] |
| Klausmeier B 2010 | 1.2 | 0.18 | 12 | 1.29 | 0.17 | 10 | 10.1% | -0.49 [-1.35, 0.36] |
| Lugade 2008 | 1.19 | 0.16 | 20 | 1.28 | 1.17 | 10 | 10.5% | -0.13 [-0.89, 0.63] |
| Lugade 2010 | 1.19 | 0.17 | 12 | 1.28 | 0.17 | 10 | 10.1% | -0.51 [-1.36, 0.35] |
| Lugade B 2010 | 1.17 | 0.17 | 11 | 1.28 | 0.17 | 10 | 9.9% | -0.62 [-1.50, 0.26] |
| Mayr 2009 | 93.07 | 27.19 | 16 | 127.8 | 11.24 | 20 | 10.4% | -1.70 [-2.48, -0.93] |
| Mayr B 2009 | 87.07 | 5.5 | 15 | 127.8 | 11.24 | 20 | 8.2% | -4.30 [-5.56, -3.04] |
| Reininga 2013 | 1.2 | 0.2 | 40 | 1.6 | 0.2 | 30 | 11.3% | -1.98 [-2.56, -1.40] |
| Shrader 2009 | 110.4 | 9.95 | 7 | 120.5 | 13.68 | 7 | 8.9% | -0.79 [-1.89, 0.31] |
| **Total (95% CI)** | | | **164** | | | **147** | **100.0%** | **-1.22 [-1.83, -0.61]** |
| Heterogeneity: Tau² = 0.78; Chi² = 48.89, df = 9 (P < 0.00001); I² = 82% | | | | | | | | |
| Test for overall effect: Z = 3.90 (P < 0.0001) | | | | | | | | |
| **Velocity 6 months vs healthy subjects** | | | | | | | | |
| Agostini 2014 | 0.92 | 0.18 | 20 | 0.99 | 0.17 | 20 | 13.8% | -0.39 [-1.02, 0.23] |
| Kanzaki 2008 | 66.2 | 5.4 | 9 | 70.2 | 5.7 | 11 | 10.1% | -0.69 [-1.60, 0.22] |
| Madsen 2004 | 1.17 | 0.2 | 10 | 1.21 | 0.12 | 9 | 10.2% | -0.23 [-1.13, 0.68] |
| Madsen B 2004 | 1.17 | 0.18 | 10 | 1.21 | 0.12 | 9 | 10.1% | -0.25 [-1.15, 0.66] |
| Nantel 2009 | 1.31 | 0.2 | 10 | 1.25 | 0.18 | 10 | 10.4% | 0.30 [-0.58, 1.18] |
| Reininga 2013 | 1.3 | 0.2 | 40 | 1.6 | 0.2 | 30 | 15.1% | -1.48 [-2.02, -0.95] |
| Tanaka 2010 | 0.792 | 0.153 | 43 | 1.018 | 0.249 | 26 | 15.3% | -1.15 [-1.67, -0.62] |
| van den Akker-Scheek 2007 | 1.14 | 0.18 | 63 | 1.32 | 0.15 | 19 | 15.1% | -1.03 [-1.56, -0.49] |
| **Total (95% CI)** | | | **205** | | | **134** | **100.0%** | **-0.69 [-1.10, -0.29]** |
| Heterogeneity: Tau² = 0.21; Chi² = 19.21, df = 7 (P = 0.008); I² = 64% | | | | | | | | |
| Test for overall effect: Z = 3.36 (P = 0.0008) | | | | | | | | |
| **Velocity 12 months vs healthy subjects** | | | | | | | | |
| Agostini 2014 | 1 | 0.22 | 20 | 0.99 | 0.17 | 20 | 14.3% | 0.05 [-0.57, 0.67] |
| Bennett 2008 | 0.99 | 0.23 | 134 | 1.34 | 0.13 | 10 | 13.8% | -1.55 [-2.21, -0.88] |
| Foucher 2007 | 1.06 | 0.11 | 28 | 1.06 | 0.13 | 25 | 15.2% | 0.00 [-0.54, 0.54] |
| Perron 2000 | 1.07 | 0.2 | 18 | 1.25 | 0.1 | 15 | 13.0% | -1.08 [-1.82, -0.34] |
| Tanaka 2010 | 0.829 | 0.143 | 43 | 1.018 | 0.249 | 26 | 15.4% | -0.99 [-1.50, -0.47] |
| Varin 2013 | 1.14 | 0.21 | 20 | 1.29 | 0.15 | 20 | 14.0% | -0.81 [-1.45, -0.16] |
| Varin B 2013 | 1.31 | 0.15 | 20 | 1.29 | 0.15 | 20 | 14.3% | 0.13 [-0.49, 0.75] |
| **Total (95% CI)** | | | **283** | | | **136** | **100.0%** | **-0.59 [-1.08, -0.11]** |
| Heterogeneity: Tau² = 0.33; Chi² = 26.09, df = 6 (P = 0.0002); I² = 77% | | | | | | | | |
| Test for overall effect: Z = 2.40 (P = 0.02) | | | | | | | | |
| **Velocity 24 months vs healthy subjects** | | | | | | | | |
| Sicard-Rosenbaum 2002 | 1.1 | 0.2 | 15 | 1.3 | 0.33 | 30 | 42.0% | -0.67 [-1.30, -0.03] |
| Talis 2008 | 1.1 | 0.2 | 27 | 1.2 | 0.2 | 27 | 58.0% | -0.49 [-1.03, 0.05] |
| **Total (95% CI)** | | | **42** | | | **57** | **100.0%** | **-0.57 [-0.98, -0.15]** |
| Heterogeneity: Tau² = 0.00; Chi² = 0.17, df = 1 (P = 0.68); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 2.69 (P = 0.007) | | | | | | | | |

**Figure 2.** A ( left) illustrates the change in walking speed following THA compared to the pre-operative status. B (right) compares post-operative THA patients to healthy individuals. Studies listed as (Author) a, b, c represent different surgical approaches used and reported in the study.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT



**A**

| | Std. Mean Difference | SE | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|
| **Step length 6 weeks** | | | | |
| Cichy 2008 | 0.24 | 0.12 | 11.7% | 0.24 [0.00, 0.48] |
| Husby 2009 | 0.55 | 0.21 | 8.3% | 0.55 [0.14, 0.96] |
| Queen 2011 | 0.86 | 0.3 | 5.8% | 0.86 [0.27, 1.45] |
| Queen 2013 | 0.74 | 0.15 | 10.5% | 0.74 [0.45, 1.03] |
| Queen b 2011 | 0.31 | 0.28 | 6.2% | 0.31 [-0.24, 0.86] |
| Queen b 2013 | 0.6 | 0.13 | 11.3% | 0.60 [0.35, 0.85] |
| Queen c 2011 | 0.25 | 0.17 | 9.8% | 0.25 [-0.08, 0.58] |
| Queen c 2013 | 0.63 | 0.13 | 11.3% | 0.63 [0.38, 0.88] |
| Reininga 2013 | -0.07 | 0.11 | 12.1% | -0.07 [-0.29, 0.15] |
| Vanden Akker-Scheek 2007 | 0.24 | 0.08 | 13.1% | 0.24 [0.08, 0.40] |
| **Total (95% CI)** | | | **100.0%** | **0.41 [0.23, 0.59]** |
| Heterogeneity: Tau² = 0.06; Chi² = 36.53, df = 9 (P < 0.0001); I² = 75% | | | | |
| Test for overall effect: Z = 4.39 (P < 0.0001) | | | | |
| **Step length 3 months** | | | | |
| da Cunha 2010 | 0.46 | 0.13 | 26.2% | 0.46 [0.21, 0.71] |
| Kiss 2012 | 0.51 | 0.2 | 16.2% | 0.51 [0.12, 0.90] |
| Kiss b 2012 | 0.34 | 0.2 | 16.2% | 0.34 [-0.05, 0.73] |
| Lavigne 2010 | 1 | 0.26 | 11.1% | 1.00 [0.49, 1.51] |
| Muller 2012 | 1 | 0.36 | 6.5% | 1.00 [0.29, 1.71] |
| Muller b 2012 | 0 | 0.33 | 7.6% | 0.00 [-0.65, 0.65] |
| Reininga 2013 | 0.53 | 0.2 | 16.2% | 0.53 [0.14, 0.92] |
| **Total (95% CI)** | | | **100.0%** | **0.52 [0.33, 0.71]** |
| Heterogeneity: Tau² = 0.02; Chi² = 8.67, df = 6 (P = 0.19); I² = 31% | | | | |
| Test for overall effect: Z = 5.26 (P < 0.00001) | | | | |
| **Step length 6 months** | | | | |
| Berman 1991 | 0.78 | 0.31 | 14.9% | 0.78 [0.17, 1.39] |
| Kiss 2012 | 0.09 | 0.3 | 15.3% | 0.09 [-0.50, 0.68] |
| Kiss b 2012 | 1.56 | 0.22 | 18.0% | 1.56 [1.13, 1.99] |
| Lavigne 2010 | 1.38 | 0.29 | 15.6% | 1.38 [0.81, 1.95] |
| Reininga 2013 | 0.79 | 0.22 | 18.0% | 0.79 [0.36, 1.22] |
| Vanden Akker-Scheek 2007 | 0.74 | 0.21 | 18.3% | 0.74 [0.33, 1.15] |
| **Total (95% CI)** | | | **100.0%** | **0.90 [0.50, 1.31]** |
| Heterogeneity: Tau² = 0.19; Chi² = 19.91, df = 5 (P = 0.001); I² = 75% | | | | |
| Test for overall effect: Z = 4.39 (P < 0.0001) | | | | |

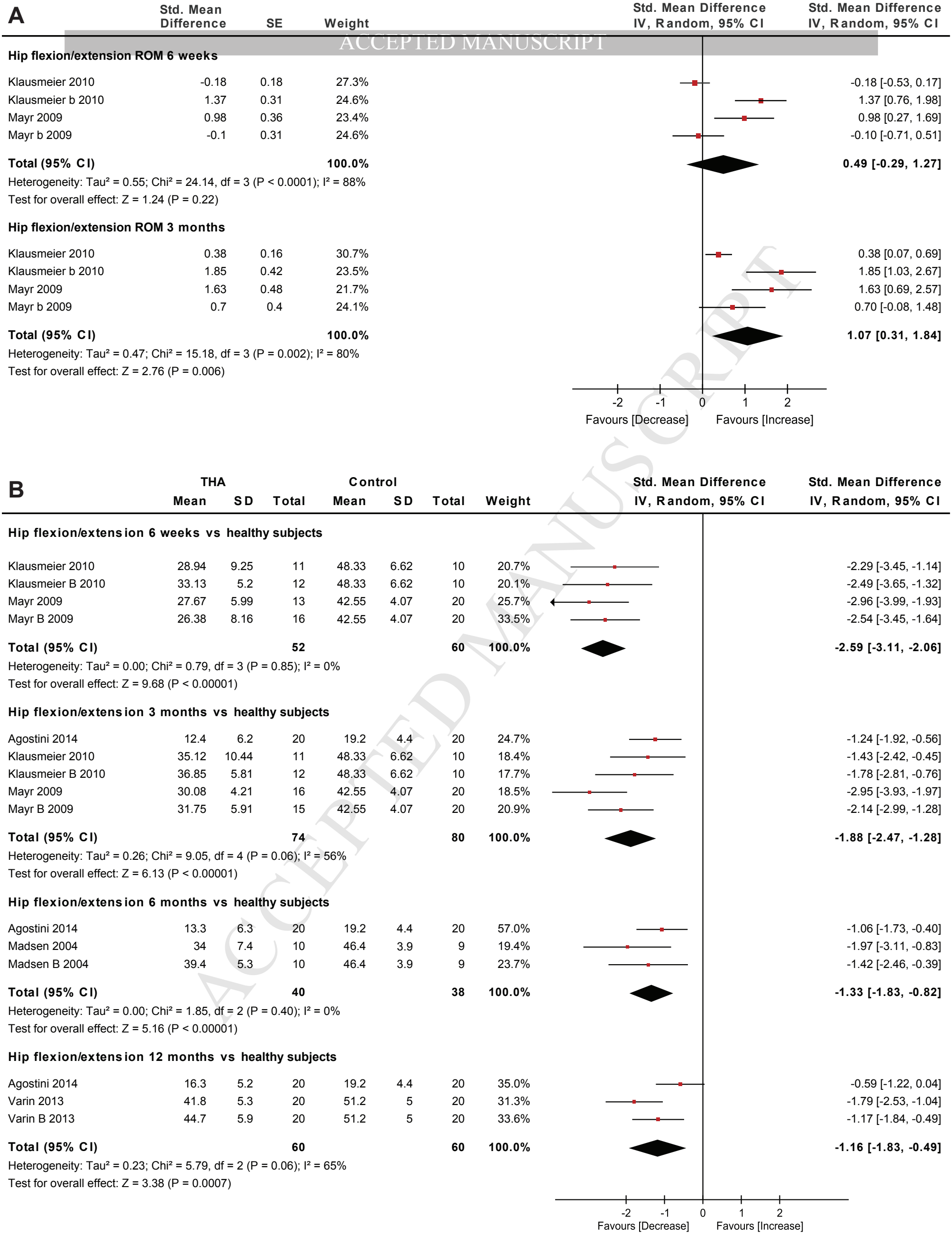
**B**

| | THA Mean | THA SD | THA Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| **Step length 6 weeks vs healthy subjects** | | | | | | | | |
| Reininga 2013 | 67.6 | 10.2 | 40 | 79.7 | 11.6 | 30 | 53.1% | -1.11 [-1.62, -0.60] |
| van den Akker-Scheek 2007 | 0.58 | 0.08 | 63 | 0.71 | 0.07 | 19 | 46.9% | -1.65 [-2.23, -1.08] |
| **Total (95% CI)** | | | **103** | | | **49** | **100.0%** | **-1.36 [-1.90, -0.83]** |
| Heterogeneity: Tau² = 0.07; Chi² = 1.95, df = 1 (P = 0.16); I² = 49% | | | | | | | | |
| Test for overall effect: Z = 4.99 (P < 0.00001) | | | | | | | | |
| **Step length 3 months vs healthy subjects** | | | | | | | | |
| Kiss 2012 | 379.6 | 38.7 | 40 | 428.2 | 61.2 | 40 | 34.6% | -0.94 [-1.40, -0.48] |
| Kiss B 2012 | 374.6 | 49.5 | 40 | 428.2 | 61.2 | 40 | 34.5% | -0.95 [-1.42, -0.49] |
| Reininga 2013 | 72.7 | 7.8 | 40 | 79.7 | 11.6 | 30 | 31.0% | -0.72 [-1.21, -0.23] |
| **Total (95% CI)** | | | **120** | | | **110** | **100.0%** | **-0.88 [-1.15, -0.60]** |
| Heterogeneity: Tau² = 0.00; Chi² = 0.57, df = 2 (P = 0.75); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 6.31 (P < 0.00001) | | | | | | | | |
| **Step length 6 months vs healthy subjects** | | | | | | | | |
| Kiss 2012 | 388.1 | 585.7 | 40 | 428.2 | 61.2 | 40 | 26.7% | -0.10 [-0.53, 0.34] |
| Kiss B 2012 | 423.5 | 39.7 | 40 | 428.2 | 61.2 | 40 | 26.7% | -0.09 [-0.53, 0.35] |
| Reininga 2013 | 75.1 | 8.5 | 40 | 79.7 | 11.6 | 30 | 24.5% | -0.46 [-0.94, 0.02] |
| van den Akker-Scheek 2007 | 0.63 | 0.1 | 63 | 0.71 | 0.07 | 19 | 22.1% | -0.84 [-1.37, -0.31] |
| **Total (95% CI)** | | | **183** | | | **129** | **100.0%** | **-0.35 [-0.68, -0.01]** |
| Heterogeneity: Tau² = 0.06; Chi² = 6.11, df = 3 (P = 0.11); I² = 51% | | | | | | | | |
| Test for overall effect: Z = 2.03 (P = 0.04) | | | | | | | | |
| **Step length 12 months vs healthy subjects** | | | | | | | | |
| Bennett 2008 | 0.53 | 0.1 | 134 | 0.69 | 0.04 | 10 | 31.2% | -1.64 [-2.31, -0.97] |
| Kiss 2012 | 411.4 | 65.4 | 40 | 428.2 | 61.2 | 40 | 34.4% | -0.26 [-0.70, 0.18] |
| Kiss B 2012 | 439.9 | 69.1 | 40 | 428.2 | 61.2 | 40 | 34.4% | 0.18 [-0.26, 0.62] |
| **Total (95% CI)** | | | **214** | | | **90** | **100.0%** | **-0.54 [-1.46, 0.38]** |
| Heterogeneity: Tau² = 0.58; Chi² = 19.79, df = 2 (P < 0.0001); I² = 90% | | | | | | | | |
| Test for overall effect: Z = 1.15 (P = 0.25) | | | | | | | | |

ACCEPTED MANUSCRIPT

**Figure 3**. A (left) illustrates the change in step length following THA compared to the pre-operative status. B (right) compares post-operative THA patients to healthy individuals. Studies listed as (Author) a, b, c represent different surgical approaches used and reported in the study.

ACCEPTED MANUSCRIPT



**A**

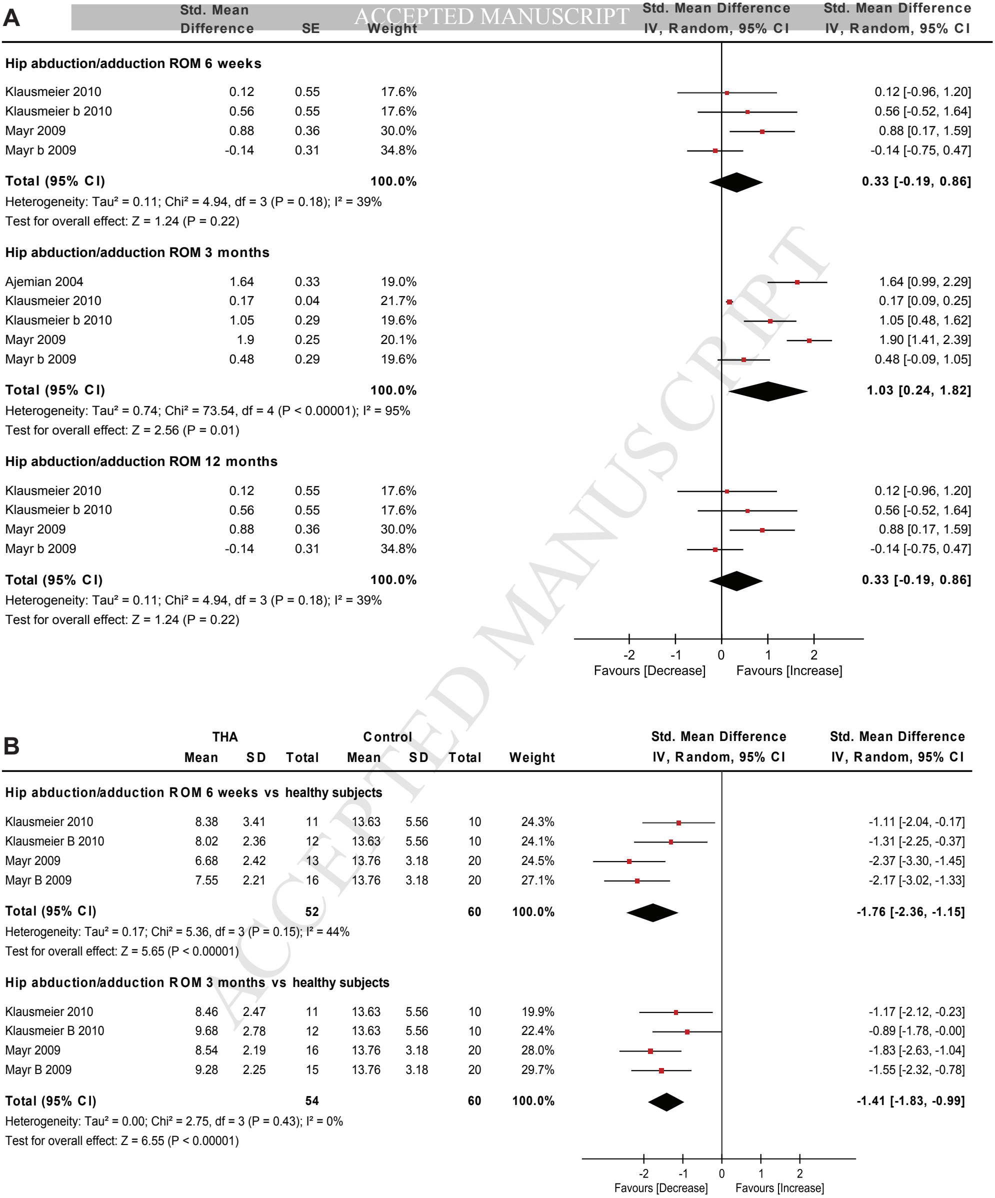
| | Std. Mean Difference | SE | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|
| **Hip flexion/extension ROM 6 weeks** | | | | |
| Klausmeier 2010 | -0.18 | 0.18 | 27.3% | -0.18 [-0.53, 0.17] |
| Klausmeier b 2010 | 1.37 | 0.31 | 24.6% | 1.37 [0.76, 1.98] |
| Mayr 2009 | 0.98 | 0.36 | 23.4% | 0.98 [0.27, 1.69] |
| Mayr b 2009 | -0.1 | 0.31 | 24.6% | -0.10 [-0.71, 0.51] |
| **Total (95% CI)** | | | **100.0%** | **0.49 [-0.29, 1.27]** |
| Heterogeneity: Tau² = 0.55; Chi² = 24.14, df = 3 (P < 0.0001); I² = 88% | | | | |
| Test for overall effect: Z = 1.24 (P = 0.22) | | | | |
| **Hip flexion/extension ROM 3 months** | | | | |
| Klausmeier 2010 | 0.38 | 0.16 | 30.7% | 0.38 [0.07, 0.69] |
| Klausmeier b 2010 | 1.85 | 0.42 | 23.5% | 1.85 [1.03, 2.67] |
| Mayr 2009 | 1.63 | 0.48 | 21.7% | 1.63 [0.69, 2.57] |
| Mayr b 2009 | 0.7 | 0.4 | 24.1% | 0.70 [-0.08, 1.48] |
| **Total (95% CI)** | | | **100.0%** | **1.07 [0.31, 1.84]** |
| Heterogeneity: Tau² = 0.47; Chi² = 15.18, df = 3 (P = 0.002); I² = 80% | | | | |
| Test for overall effect: Z = 2.76 (P = 0.006) | | | | |

**B**

| | THA | | | Control | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Total | Mean | SD | Total | Weight | Std. Mean Difference IV, Random, 95% CI |
| **Hip flexion/extension 6 weeks vs healthy subjects** | | | | | | | | |
| Klausmeier 2010 | 28.94 | 9.25 | 11 | 48.33 | 6.62 | 10 | 20.7% | -2.29 [-3.45, -1.14] |
| Klausmeier B 2010 | 33.13 | 5.2 | 12 | 48.33 | 6.62 | 10 | 20.1% | -2.49 [-3.65, -1.32] |
| Mayr 2009 | 27.67 | 5.99 | 13 | 42.55 | 4.07 | 20 | 25.7% | -2.96 [-3.99, -1.93] |
| Mayr B 2009 | 26.38 | 8.16 | 16 | 42.55 | 4.07 | 20 | 33.5% | -2.54 [-3.45, -1.64] |
| **Total (95% CI)** | | | **52** | | | **60** | **100.0%** | **-2.59 [-3.11, -2.06]** |
| Heterogeneity: Tau² = 0.00; Chi² = 0.79, df = 3 (P = 0.85); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 9.68 (P < 0.00001) | | | | | | | | |
| **Hip flexion/extension 3 months vs healthy subjects** | | | | | | | | |
| Agostini 2014 | 12.4 | 6.2 | 20 | 19.2 | 4.4 | 20 | 24.7% | -1.24 [-1.92, -0.56] |
| Klausmeier 2010 | 35.12 | 10.44 | 11 | 48.33 | 6.62 | 10 | 18.4% | -1.43 [-2.42, -0.45] |
| Klausmeier B 2010 | 36.85 | 5.81 | 12 | 48.33 | 6.62 | 10 | 17.7% | -1.78 [-2.81, -0.76] |
| Mayr 2009 | 30.08 | 4.21 | 16 | 42.55 | 4.07 | 20 | 18.5% | -2.95 [-3.93, -1.97] |
| Mayr B 2009 | 31.75 | 5.91 | 15 | 42.55 | 4.07 | 20 | 20.9% | -2.14 [-2.99, -1.28] |
| **Total (95% CI)** | | | **74** | | | **80** | **100.0%** | **-1.88 [-2.47, -1.28]** |
| Heterogeneity: Tau² = 0.26; Chi² = 9.05, df = 4 (P = 0.06); I² = 56% | | | | | | | | |
| Test for overall effect: Z = 6.13 (P < 0.00001) | | | | | | | | |
| **Hip flexion/extension 6 months vs healthy subjects** | | | | | | | | |
| Agostini 2014 | 13.3 | 6.3 | 20 | 19.2 | 4.4 | 20 | 57.0% | -1.06 [-1.73, -0.40] |
| Madsen 2004 | 34 | 7.4 | 10 | 46.4 | 3.9 | 9 | 19.4% | -1.97 [-3.11, -0.83] |
| Madsen B 2004 | 39.4 | 5.3 | 10 | 46.4 | 3.9 | 9 | 23.7% | -1.42 [-2.46, -0.39] |
| **Total (95% CI)** | | | **40** | | | **38** | **100.0%** | **-1.33 [-1.83, -0.82]** |
| Heterogeneity: Tau² = 0.00; Chi² = 1.85, df = 2 (P = 0.40); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 5.16 (P < 0.00001) | | | | | | | | |
| **Hip flexion/extension 12 months vs healthy subjects** | | | | | | | | |
| Agostini 2014 | 16.3 | 5.2 | 20 | 19.2 | 4.4 | 20 | 35.0% | -0.59 [-1.22, 0.04] |
| Varin 2013 | 41.8 | 5.3 | 20 | 51.2 | 5 | 20 | 31.3% | -1.79 [-2.53, -1.04] |
| Varin B 2013 | 44.7 | 5.9 | 20 | 51.2 | 5 | 20 | 33.6% | -1.17 [-1.84, -0.49] |
| **Total (95% CI)** | | | **60** | | | **60** | **100.0%** | **-1.16 [-1.83, -0.49]** |
| Heterogeneity: Tau² = 0.23; Chi² = 5.79, df = 2 (P = 0.06); I² = 65% | | | | | | | | |
| Test for overall effect: Z = 3.38 (P = 0.0007) | | | | | | | | |

**Figure 4.** A (top) illustrates the change in sagittal plane hip flexion/extension ROM following THA compared to the pre-operative status. B (bottom) compares post-operative THA patients to healthy individuals. Studies listed as (Author) a, b, c represent different surgical approaches used and reported in the study

ACCEPTED MANUSCRIPT



**A**

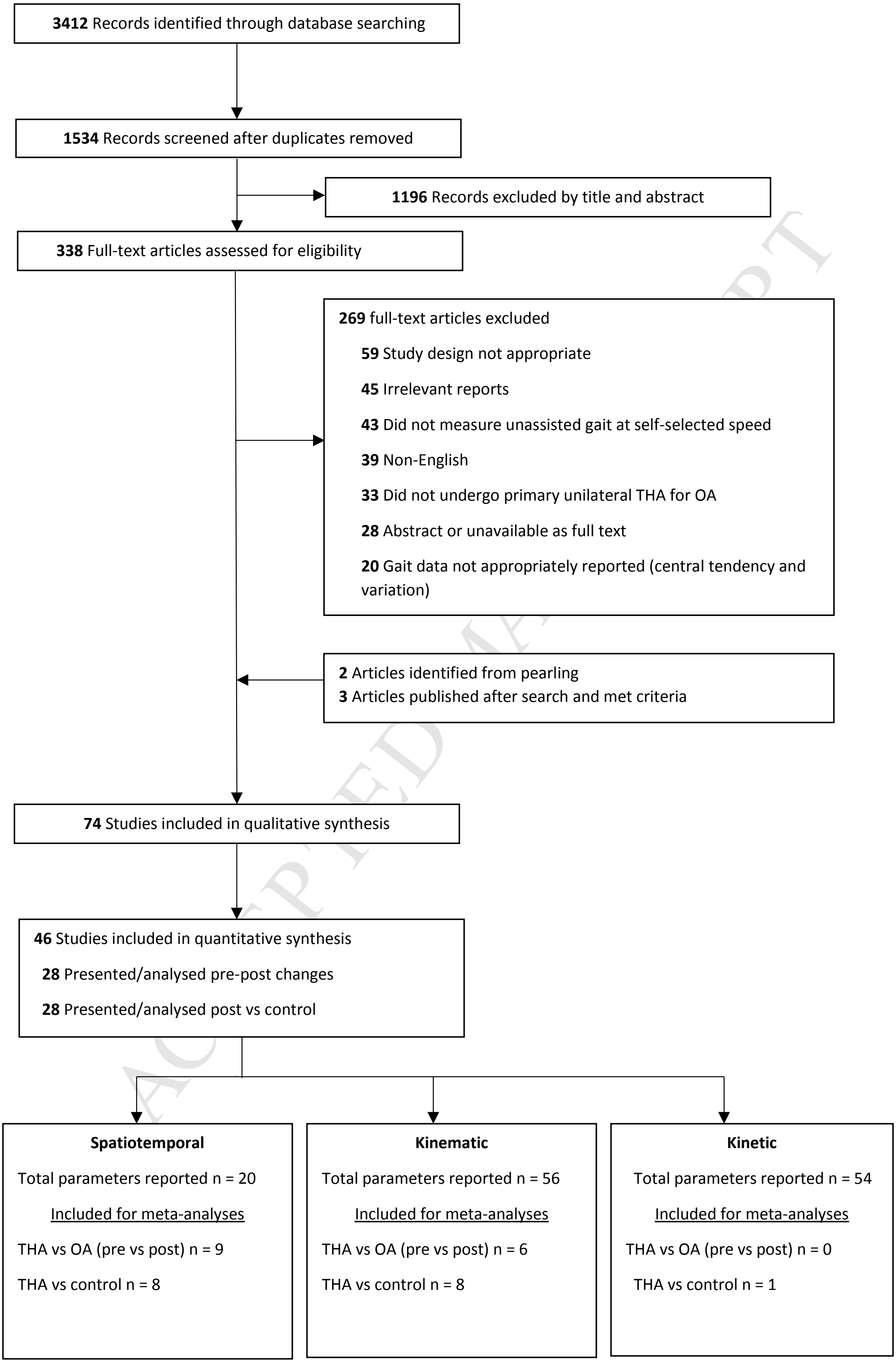
| | Std. Mean Difference | SE | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|
| **Hip abduction/adduction ROM 6 weeks** | | | | |
| Klausmeier 2010 | 0.12 | 0.55 | 17.6% | 0.12 [-0.96, 1.20] |
| Klausmeier b 2010 | 0.56 | 0.55 | 17.6% | 0.56 [-0.52, 1.64] |
| Mayr 2009 | 0.88 | 0.36 | 30.0% | 0.88 [0.17, 1.59] |
| Mayr b 2009 | -0.14 | 0.31 | 34.8% | -0.14 [-0.75, 0.47] |
| **Total (95% CI)** | | | **100.0%** | **0.33 [-0.19, 0.86]** |
| Heterogeneity: Tau² = 0.11; Chi² = 4.94, df = 3 (P = 0.18); I² = 39% | | | | |
| Test for overall effect: Z = 1.24 (P = 0.22) | | | | |
| **Hip abduction/adduction ROM 3 months** | | | | |
| Ajemian 2004 | 1.64 | 0.33 | 19.0% | 1.64 [0.99, 2.29] |
| Klausmeier 2010 | 0.17 | 0.04 | 21.7% | 0.17 [0.09, 0.25] |
| Klausmeier b 2010 | 1.05 | 0.29 | 19.6% | 1.05 [0.48, 1.62] |
| Mayr 2009 | 1.9 | 0.25 | 20.1% | 1.90 [1.41, 2.39] |
| Mayr b 2009 | 0.48 | 0.29 | 19.6% | 0.48 [-0.09, 1.05] |
| **Total (95% CI)** | | | **100.0%** | **1.03 [0.24, 1.82]** |
| Heterogeneity: Tau² = 0.74; Chi² = 73.54, df = 4 (P < 0.00001); I² = 95% | | | | |
| Test for overall effect: Z = 2.56 (P = 0.01) | | | | |
| **Hip abduction/adduction ROM 12 months** | | | | |
| Klausmeier 2010 | 0.12 | 0.55 | 17.6% | 0.12 [-0.96, 1.20] |
| Klausmeier b 2010 | 0.56 | 0.55 | 17.6% | 0.56 [-0.52, 1.64] |
| Mayr 2009 | 0.88 | 0.36 | 30.0% | 0.88 [0.17, 1.59] |
| Mayr b 2009 | -0.14 | 0.31 | 34.8% | -0.14 [-0.75, 0.47] |
| **Total (95% CI)** | | | **100.0%** | **0.33 [-0.19, 0.86]** |
| Heterogeneity: Tau² = 0.11; Chi² = 4.94, df = 3 (P = 0.18); I² = 39% | | | | |
| Test for overall effect: Z = 1.24 (P = 0.22) | | | | |

**B**

| | THA | | | Control | | | | Std. Mean Difference |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI |
| **Hip abduction/adduction ROM 6 weeks vs healthy subjects** | | | | | | | | |
| Klausmeier 2010 | 8.38 | 3.41 | 11 | 13.63 | 5.56 | 10 | 24.3% | -1.11 [-2.04, -0.17] |
| Klausmeier B 2010 | 8.02 | 2.36 | 12 | 13.63 | 5.56 | 10 | 24.1% | -1.31 [-2.25, -0.37] |
| Mayr 2009 | 6.68 | 2.42 | 13 | 13.76 | 3.18 | 20 | 24.5% | -2.37 [-3.30, -1.45] |
| Mayr B 2009 | 7.55 | 2.21 | 16 | 13.76 | 3.18 | 20 | 27.1% | -2.17 [-3.02, -1.33] |
| **Total (95% CI)** | | | **52** | | | **60** | **100.0%** | **-1.76 [-2.36, -1.15]** |
| Heterogeneity: Tau² = 0.17; Chi² = 5.36, df = 3 (P = 0.15); I² = 44% | | | | | | | | |
| Test for overall effect: Z = 5.65 (P < 0.00001) | | | | | | | | |
| **Hip abduction/adduction ROM 3 months vs healthy subjects** | | | | | | | | |
| Klausmeier 2010 | 8.46 | 2.47 | 11 | 13.63 | 5.56 | 10 | 19.9% | -1.17 [-2.12, -0.23] |
| Klausmeier B 2010 | 9.68 | 2.78 | 12 | 13.63 | 5.56 | 10 | 22.4% | -0.89 [-1.78, -0.00] |
| Mayr 2009 | 8.54 | 2.19 | 16 | 13.76 | 3.18 | 20 | 28.0% | -1.83 [-2.63, -1.04] |
| Mayr B 2009 | 9.28 | 2.25 | 15 | 13.76 | 3.18 | 20 | 29.7% | -1.55 [-2.32, -0.78] |
| **Total (95% CI)** | | | **54** | | | **60** | **100.0%** | **-1.41 [-1.83, -0.99]** |
| Heterogeneity: Tau² = 0.00; Chi² = 2.75, df = 3 (P = 0.43); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 6.55 (P < 0.00001) | | | | | | | | |

**Figure 5.** A (top) illustrates the change in coronal plane hip abduction/adduction ROM following THA compared to the pre-operative status. B (bottom) compares post-operative THA patients to healthy individuals.Studies listed as (Author) a, b, c represent different surgical approaches used and reported in the study

ACCEPTED MANUSCRIPT



ACCEPTED MANUSCRIPT