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The association of leg length and offset reconstruction after total hip arthroplasty with clinical outcomes

Stijn A.A.N. Bolink, MD; PhD[1]; Erik Lenguerrand, PhD[1]; Luke R. Brunton[1]; Nicole Hinds[1]; Vikki Wylde, PhD[1]; Ide C. Heyligers, MD; PhD[2]; Ashley W. Blom, MD; PhD[1]; Mike R. Whitehouse, MD; PhD[1]; Bernd Grimm, PhD[3].

[1] Musculoskeletal Research Unit, School of Clinical Sciences, University of Bristol, Southmead Hospital, Bristol BS10 5NB, United Kingdom

[2] Zuyderland Medical Center Heerlen, Dept of Orthopaedics, Henri Dunantstraat 5, 6419 PC, Heerlen, The Netherlands.

[3] The Human Motion Institute, Hohenlindener Str. 1, 81677 Munich, Germany.

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Corresponding author:

Stijn A.A.N. Bolink, MD, PhD

Musculoskeletal Research Unit, School of Clinical Sciences, University of Bristol, United Kingdom

<u>Address:</u> Musculoskeletal Research Unit, Learning and Research building, Southmead Road, Bristol BS10 5NB, United Kingdom

<u>E-mail:</u> stijn.bolink@mail.com

Abstract

Background: Restoring native hip anatomy and biomechanics is important to create a well-functioning hip arthroplasty. This study investigated the association of hip offset and leg length after hip arthroplasty with clinical outcomes, including patient reported outcome measures, the Trendelenburg Test and gait analysis.

Methods: In 77 patients undergoing primary hip arthroplasty for osteoarthritis (age mean=65 SD=11 years; BMI mean=27 SD=5 kg/m^2), hip offset and leg length discrepancy were measured on anteroposterior radiographs. The Western Ontario & McMaster Universities Osteoarthritis Index, the Trendelenburg Test and gait were assessed preoperatively, and at 3 and 12 months postoperatively. An inertial measurement unit was used to derive biomechanical parameters, including spatiotemporal gait parameters and tilt angles of the pelvis. Relationships between radiographic and functional outcomes were investigated, and subgroups of patients with >15% decreased and increased femoral offset were analysed separately.

Findings: patient-reported function scores and clinical tests demonstrated a few significant, weak correlations with radiographic outcomes (Spearman's ρ range =0.26-0.32; p<0.05). Undercorrection of femoral offset was associated with lower patient-reported function scores and with more step irregularity as well as step asymmetry during gait. Postoperative leg length inequality was associated with increased frontal plane tilt angle of the pelvis during the Trendelenburg Test and increased sagittal plane motion of the pelvis during gait. Femoral offset subgroups demonstrated no significant differences for patient-reported function scores and outcomes of the Trendelenburg Test and gait analysis.

Interpretation: Reduced hip offset and leg length dicrepancy following hip arthroplasty seem to be marginally associated with worse clinical outcomes.

1. Introduction

Total hip arthroplasty (THA) is a well-established treatment for patients with advanced hip osteoarthritis (OA), reducing pain and improving function for the majority of patients (1). To create a well-functioning THA, it is important to restore the native hip biomechanics by proper implant reconstruction (2). Hip offset and leg length are regarded as the most important biomechanical characteristics and can be evaluated on plain radiographs (3). Reconstructing offset correlates with improved abductor muscle function and stability (4, 5). Leg length discrepancy (LLD) after THA most commonly involves over-lengthening (6) and may cause low back pain, discomfort, instability, limping and nerve palsies (3), especially when magnitudes exceed 1.5cm (7).

Although proper implant reconstruction improves the biomechanical function of the hip, existing evidence on the association with clinical outcomes is not consistent. Several studies using patient-reported outcome measures (PROMs) have found no association with radiographic measurements after THA (1, 8-14) whereas others have reported marginally significant correlations (7, 9, 15, 16). In addition to PROMs, functional tests can be used to assess outcomes after THA. Asayama et al. (5) demonstrated that a 15% decrease in femoral offset generates weakness of the abductor muscles and correlates with the frontal plane tilt angle of the pelvis during the Trendelenburg test (17). Sariali et al. (18) found significant gait alterations in patients with more than 15% decreased postoperative femoral offset while Zhang et al (16) and Li et al (19) reported significant gait alterations between patients with variable LLD after THA. Because PROMs are subjective measures, suffer from a ceiling effect, and may lack sufficient sensitivity to demonstrate a difference in clinical outcomes (18, 20), functional tests may be better discriminators to capture functional impairments in relation to changes of the reconstructed hip joint position after THA. No study has concurrently used PROMs and functional tests to compare the outcome of THA according to pre- and postoperative hip offset and LLD.

The primary aim of this study was to investigate whether restoration of the native hip anatomy after THA, in terms of hip offset and LLD, results in better postoperative function assessed by PROMs and functional tests. A second aim of the study was to investigate whether a change of more than 15% in femoral offset after THA would result in worse or better functional outcomes.

2. Methods

2.1 Study participants

Patient data were from a single centre prospective UK cohort study comparing outcome measures in patients undergoing joint replacement (ADAPT study: UKCRN ID 8311 (21-23)). Ethics approval was obtained for this study and all participants provided informed, written consent. From this cohort, patients listed for primary THA (n=77; male/female=37/40; age mean=65 SD=11 years; BMI mean=27 SD=5kg/m^2) were selected. All THA's were performed via a posterolateral approach. Routine anteroposterior radiographs of the hips with knees extended and hips internally rotated were assessed preoperatively and postoperatively. Prior to surgery, all hips were templated on the available radiographs to measure the size of the implants to be used and to aim for an adequate reconstruction of offset and leg length. Patients completed PROMs and performed functional tests preoperatively (median=-23 days; IQR =[-35;-12] days), and at 3 months (median=105 days; IQR =[99;114] days) and 12 months (median=380 days; IQR =[369;400] days) postoperatively.

2.2 Radiographic measurements

Radiographic measurements were performed according to the method of Parry et al. (2) using standardised anatomical landmarks (13, 24). Femoral offset (FO) was measured as the perpendicular distance between the centre of rotation of the femoral head, and the long axis of the femur (line A, figure 1). Acetabular offset (AO) was measured as the distance between the centre of rotation of the femoral head and a vertical reference line drawn through the centre of the acetabular teardrop (line B, figure 1). The sum of these two values (A + B) was defined as the global offset (GO). Leg length was calculated using the trochanteric method described by Konyves and Bannister (13) with leg length discrepancy (LLD) as the addition of the vertical distance between the interteardrop line and the most medial visible point on the lesser trochanter (line C, figure 1). With regards to offset reconstruction, two measurements were used: 1) postoperative ratio between left and right hip ($\frac{\text{offset left hip}}{\text{offset right hip}}$) and 2) ratio between preoperative and postoperative offset in the operated hip ($\frac{\text{offset postop}}{\text{offset preop}}$) with a value below 1 indicating offset undercorrection. For leg length, two measurements were used: 1) absolute postoperative LLD (mm) between left and right leg; 2) absolute change (mm) between preoperative and postoperative leg length in the operated leg.

[Insert Figure 1]

Figure 1. Radiographic measurements based on anatomical landmarks. Femoral offset represents the perpendicular distance between the centre of rotation of the femoral head and the long axis of the femur (A). Acetabular offset represents the distance between the centre of rotation of the femoral head and a vertical reference line drawn through the centre of the acetabular teardrop (B). Leg length discrepancy represents the addition of the distance between a line drawn intersecting the acetabular teardrop and the most medial visible point on the lesser trochanter (C), compared to the contralateral limb.

2.3 Patient-reported outcome measures (PROMs)

The WOMAC score was used as it is well validated, reliable, easy to administer and has been widely adopted (25). It provides information on the patient's perception of pain (5 items), stiffness (2 items) and physical function (17 items) and each item is scored on a 5-point ordered response scale. Only the WOMAC function subscore was used and transformed to a 0-100 score, with 0 representing the worst score and 100 representing the best score (26).

2.4 Fucntional tests

Functional tests that were assessed included the Trendelenburg Test and a 20m walking test. An inertial measurement unit (IMU; MicroStrain® Inertia-Link®; Williston, United States of America; 41 ×

63 × 24 mm; 39 g;) (27) was worn at the dorsal side of the pelvis to derive spatiotemporal gait parameters and orientation angles (°) of the pelvis (28). Data analysis was performed running analysis algorithms in MATLAB® (MathWorks®) (27).

(1) Trendelenburg Test

The Trendelenburg Test is the most widely accepted clinical test to assess hip abductor muscle function. In the Trendelenburg Test, subjects stand on one leg, elevate the pelvis on the nonstance side and try to maintain this position for 30 seconds (29). The assessment is the measurement of the frontal plane tilt angle of the pelvis (i.e. pelvic obliquity). The test is evaluated as *negative* if the pelvis on the nonstance side can be elevated as high as hip abduction on the stance side allows. The test is evaluated as *positive* if this cannot be done. If the pelvis can be lifted on command, but cannot be maintained in that position for 30 seconds, it is evaluated as a *delayed positive* Trendelenburg Test. A negative Trendelenburg Test reflects desirable hip abductor muscle function and stable gait, whereas a positive Trendelenburg Test is associated with hip abductor dysfunction and gait disturbances (17, 18). Variations in hip flexion and foot positioning demonstrated an effect on the magnitude of the frontal plane pelvic tilt angle during conduct of the Trendelenburg Test (Figure 2). Therefore, the Trendelenburg Test was further standardized and all participants were asked to raise one leg with 30° flexion in the hip joint, keep the raised foot anterior to the stance foot and maintain this position with both hands resting on the back of a chair for balance. The frontal plane pelvic tilt angle was defined as the median pelvic angle (°) during 30 seconds for which a negative value indicates a pelvic drop on the non-stance side.

[Insert Figure 2]

Figure 2: waveforms for pelvic obliquity during the Trendelenburg Test: (A) representative waveform of a healthy person; (B) three hip flexion angles: 30°-60°-90° (I-II-III resp.); (C) three foot positions: anterior to the stance foot (I), parallel to stance foot (II), posterior to the stance foot (III).

(2) Gait

Analysis of gait is widely accepted as an important objective measure of functional outcome following THA (30). In the current study, participants walked a 20m distance at preferred speed, in an indoor environment along a straight flat corridor. (31). None of the participants used a walking aid. Outcome measures include spatiotemporal gait parameters derived by heel strike (HS) detections from the raw anteroposterior acceleration signal (32) and range of motion (RoM) of the pelvis in sagittal and frontal plane (33).

[Insert Figure 3]

Figure 3: typical gait signals and automated peak detection (Matlab): (A) anteroposterior acceleration signal with heel strike detection; (B) frontal plane pelvic angles and peak detection to calculate range of motion.

2.5 Statistical analysis

Based on the threshold of a 15% (i.e. 0.15) difference in postoperative FO, patients were stratified into three subgroups: 1) restored FO (0.85-1.15); 2) decreased FO (<0.85) and 3) increased FO (>1.15). PROMs and functional tests were compared between these subgroups. Study variables were described for the entire sample (n=77) and by FO subgroup using the median and interquartile range (IQR; 25th and 75th percentile). Group comparisons of continuous variables were conducted using Kruskal-Wallis test followed by Dunn's test to allow multiple pairwise comparisons. The relationships between each radiographic measurement and functional outcome measure were investigated using the Spearman's rho (ρ) correlation coefficient. Correlations were interpreted as follows: <0.2: none; 0.21–0.5 weak; 0.51–0.8: moderate; >0.81: strong (34). Univariate linear multi-level regression analyses were used to model the longitudinal outcome trajectories and to conduct FO subgroup comparisons. A p-value of

<0.05 was considered statistically significant. Stata 14.1 (StataCorp, College Station, TX) and MlwinN v2.35 were used ((35)).

3. Results

Postoperative radiographs demonstrated a median FO of 38mm (IQR 33-43), AO of 31mm (IQR 28-33), GO of 70mm (IQR 63-75) and LLD of 6mm (IQR 3-8) (table 1). A decrease in FO by more than 15% was found in 16 of 77 (21%) patients postoperatively. More than 15% increase in FO was found in 14 of 77 (18%) patients postoperatively. In 47 of 77 (61%) patients, FO was restored adequately as it showed fewer than 15% decrease or increase (i.e. 0.85-1.15) postoperatively. There were no significant differences in LLD between subgroups and no significant differences were found for age, BMI and gender distribution (table 1).

Table 1: demographic variables and radiographic outcomes by femoral offset (FO) status group. P-values correspond with the comparisons between patients with restored FO (0.85-1.15) and patients with more than 15% decreased (<0.85) or increased (>1.15) FO.

WOMAC function scores after THA demonstrated significant but weak correlations with the pre- to postoperative changes in FO and GO (table 2). A smaller postop:preop ratio, indicating an undercorrection of femoral offset, was significantly but weakly associated with lower (i.e. worse) WOMAC function scores at 3 and 12 months postoperatively (Spearman's $\rho=0.32$ and 0.29 resp. $p<0.05$). Furthermore, a smaller postop:preop ratio in GO, indicating an undercorrection of global offset, was significantly but weakly correlated with lower WOMAC function scores at 12 months postoperatively (Spearman's $\rho=0.27$; $p<0.05$).

Table 2: Spearman's rho (ρ) correlation coefficients between radiographic parameters and functional outcome parameters in the total patient group (n=77). Significant correlations ($p<0.05$) are marked with * and highlighted in grey. RoM (range of motion); L:R (Left:Right); Post:Pre (Postoperative:Preoperative).

[Insert Figure 4]

Figure 4. Postoperative trajectories of WOMAC function scores in patients with restored (0.85-1.15), decreased (<0.85) and increased (>1.15) femoral offset.

Functional tests equally demonstrated a few statistically significant but weak correlations with various postoperative radiographic measurements (Spearman's ρ range = 0.26 – 0.32; $p<0.05$; table 2). Postoperative asymmetry of AO and GO was weakly correlated with the frontal plane tilt angle of the pelvis during the Trendelenburg Test at 12 months postoperatively (Spearman's $\rho = 0.26$ and 0.26 resp. $p<0.05$) In addition, the postop:preop ratio of GO was weakly correlated with the outcome of the Trendelenburg Test (Spearman's $\rho = 0.29$; $p<0.05$) at 12 months, indicating that reduced GO is associated with smaller frontal plane tilt angles of the pelvis. Furthermore, postoperative LLD demonstrated a significant but weak correlation at 3 months after THA (Spearman's $\rho = 0.26$; $p<0.05$), for which a larger leg length difference seems to be associated with a larger frontal plane tilt angle of the pelvis.

For gait, changes in FO following THA demonstrated significant but weak correlations with step time irregularity (Spearman's $\rho= -0.30$; $p<0.05$) and step time asymmetry (Spearman's $\rho = -0.31$; $p<0.05$) 12 months postoperatively, indicating that gait irregularity and asymmetry increases when postoperative FO decreases. Furthermore, postoperative LLD seemed to have a minor influence on the RoM in sagittal plane of the pelvis during gait 3 months after THA (Spearman's $\rho= 0.32$; $p<0.05$).

In the subgroup analyses, WOMAC function scores did not demonstrate a significant difference for patients with more than 15% decreased or 15% increased FO after THA. Furthermore, no differences between patients with decreased, increased, or adequately restored FO were found for outcomes of the Trendelenburg Test and gait analysis. (table 3).

Table 3: Subgroup comparisons for all functional outcome parameters preoperatively showing the median. interquartile range (IQR) and p-values corresponding with the level of significance associated with comparison between the restored (0.85-1.15), the decreased (<0.85) or the increased (>1.15) FO group.

4. Discussion

This study has demonstrated that variations in hip offset and leg length after THA, are marginally associated to subjective patient-reported and objective functional outcome measures. The main findings were that reduced femoral offset seems to be associated with lower WOMAC function scores and with more gait irregularity as well as gait asymmetry. However, the observed associations are weak and not likely to represent substantial clinical differences. Moreover, patients with more than 15% decreased femoral offset did not seem to report worse WOMAC function scores nor did they perform worse on the functional tests.

4.1 Radiographic measurements

Hip offset and leg length are widely used to define adequate reconstruction after THA on plain radiographs. Typically the centre of rotation of the hip is medialized during THA, decreasing AO. This is compensated for by increasing FO (36). Increasing FO with a longer femoral neck may result in leg lengthening and if overcorrected, can lead to increased tension on the abductor muscles, causing pain, impaired function and perceived LLD (1, 37). In this study's cohort, the AO was decreased by 11%, FO was increased by 3% and GO was decreased by 5%. The median leg length was increased by 4mm resulting in a median LLD of 6mm. These findings are typical of those presented in the literature (2, 9, 17, 38) (37).

4.2 PROMs

Most studies to date have suggested that PROMs lack sufficient sensitivity to capture differences in hip joint reconstruction (1, 8, 10-14, 18). In the current study, WOMAC function scores were significantly but weakly correlated to the differences between pre- and postoperative FO and GO. In particular, patients with less adequate FO reconstruction following THA were associated with worse WOMAC function scores at 3 and 12 months. However, FO subgroups demonstrated no significant differences in WOMAC function scores. Bjordal et al. (1) compared normal and increased (>5mm) FO to the Harris Hip Score (HHS) and Hip Osteoarthritis Outcome Score (HOOS) and found no significant differences. Wylde et al. (8) found no differences in WOMAC scores between patients with normal, increased (>10mm) or decreased (<10mm) FO after THA. Cassidy et al. (9) compared WOMAC function scores 12 months after THA between patients (n=31) with more than 5mm decreased FO compared to the contralateral side, patients (n=163) with restored FO and patients (n=55) with more than 5mm increased FO. They reported statistically significant differences with worse outcomes in the decreased FO group but there was substantially greater heterogeneity in indication for THA in their cohort. Regarding LLD, Mahmood et al. (15) found significantly less improvement in WOMAC scores 12-15 months after THA for patients with more than 9mm leg lengthening compared to patients with more than 5mm shortening. However, no significant differences were found when comparing to patients with adequate leg length restoration. Zhang et al. (16) compared postoperative Harris Hip Scores (HHS) between patients with a LLD <10mm, LLD of 10-20mm and LLD >20mm, and found improved HHS for patients with smaller LLD at 6 months postoperatively. Beard et al. (39) found no statistically significant differences in Oxford Hip Scores (OHS) for patients with increased LLD (>10mm) at 3 months and 12 months postoperatively. The mean LLD after THA varies widely (15, 37) but the difference is less than 10 mm in 97% of cases (40). Konyves et al. (13) reported comparable mean lengthening of 3.5mm in their cohort of 90 patients following THA, with 62% of their patients lengthened by a mean of 9mm, and found no correlations with the OHS after THA. Although the magnitude of LLD in our cohort was rather small in comparison to most other studies, our findings emphasize that variations in postoperative LLD below 10mm do not result in better or worse patient-reported outcomes.

4.3 Functional tests

Objective assessment with functional tests is considered more likely to characterize the true functional recovery after THA than PROMs (41), and could provide valuable information regarding deficits that persist after surgery (20). Functional tests with IMU based motion analysis would allow more detailed biomechanical evaluation of physical function than PROMs (33, 42). Analysis of gait is the most widely applied functional test following THA. We found a few significant, but weak correlations between radiographic measurements and gait parameters. In our study cohort, patients with less adequate FO reconstruction following THA were associated with larger step time irregularity and asymmetry during gait. However, no significant gait alterations were observed between the FO subgroups. In contrast, Sariali et al. (18) compared gait between similar subgroups one year after THA, and found significantly lower range of motion at the knee and lower maximal swing speed in the operated compared to the contralateral limb for patients with decreased FO. Furthermore, in this study's cohort, postoperative LLD was associated with more pelvic RoM in sagittal plane 3 months after THA. Zhang et al. (16) found significant gait alterations (i.e. slower walking speed, longer single support time and shorter foot-off time) 6 months after THA in patients with larger LLD (>10mm), but no difference at 12 months postoperatively. Li et al. (19) found lower walking speed, reduced stride length, reduced ground reaction force and impaired hip RoM during gait in patients with a larger LLD 12 months after THA. The inequality in magnitude of postoperative LLD between our cohort and those reported by previously mentioned authors may however limit subgroup comparison. Our findings suggest that variations in postoperative LLD below 10mm do not result in significant gait alterations.

The Trendelenburg Test is the most widely accepted clinical test to assess hip abductor muscle function. It measures the frontal plane tilt angle of the pelvis during single leg stance. Asayama et al. (17) studied the frontal plane tilt angle of the pelvis in the Trendelenburg Test and its relation to femoral offset after THA. Their study included 34 primary THA's in 30 patients with a minimum follow-up of 2 years. The tilt angle of the pelvis was measured with a magnetic sensor system, defined by subtracting the tilt angle at 30 seconds after starting the Trendelenburg Test from the tilt angle at 0 seconds. Adequate restoration of femoral offset correlated positively with this tilt angle of the pelvis (r=0.407). In another study by Asayama et al. (5), a significant correlation (r=0.491) was reported between the restoration of femoral offset after THA and isometric hip abductor strength, measured by a dynamometer. In the current study, we standardized the Trendelenburg Test with regards to foot position and hip flexion, and calculated the median frontal plane tilt angle of the pelvis during 30 seconds. We found no significant correlation with restoration of FO in a cohort op 77 patients following THA, nor did we find a significant difference between patients with adequately restored FO and more than 15% decrease in FO after THA. However, we did find a significant but weak association between GO and the outcome of the Trendelenburg Test, suggesting that patients with a smaller reconstructed GO following THA cannot lift their pelvis to the same extent as patients with adequately reconstructed GO. In the literature, compensation mechanisms during the Trendelenburg Test have been described in patients with impaired hip abductor muscle function to achieve a horizontal pelvis (29). Shifting the centre of mass towards the stance side, as well as lateral trunk lean, reduces the body weight lever arm and therefore reduces the force of the hip abductor muscles required to maintain a horizontal pelvis. Furthermore, seeking balance by arm support on the nonstance side allows active shoulder adduction to compensate for a pelvic drop. Therefore, Hardcastle and Nade (29) standardized the Trendelenburg test and allowed arm support for balance only at the stance side. The modifications of the Trendelenburg Test in the current study, allowing support with both arms and calculating the median tilt angle of the pelvis during the test, may potentially have accounted for false negative results.

<u>Limitations</u>

Limitations in the reliability of radiographic measurements from bi-dimensional data may be present. Femoral stem anteversion and rotation of the hip could alter offset measurements (43) and the method described by Konyves et al (13) to calculate leg length, which we adopted, can be effected by pelvic positioning (15). The WOMAC score that was used in the current study has demonstrated fewer distinct activity concepts compared to other PROMs, such as the OHS (Oxford Hip Score) and HOOS (Hip Osteoarthritis Outcome Score) (44). Although the functional tests that were used in the current study reflect on hip abductor muscle function, we did not measure hip abductor muscle strength itself. Finally, the small sample size of our FO subgroups may lack power for the functional differences observed to become statistically significant.

5. Conclusions

Restoring native hip anatomy and biomechanics is important to create a well-functioning THA. Reduced hip offset and a leg length dicrepancy following THA seem to be associated with worse functional outcomes. However, alterations in offset and leg length that are generally considered acceptable and represented by this study's cohort, seem to have a rather small impact on functional outcomes.

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