Should we navigate?
Trochanteric pain syndrome is the main reason for low satisfaction, but not related to accuracy of anterior approach THR

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Abstract

Background Reconstruction of leg length and hip offset appears a self-evident goal for total hip arthroplasty (THA) that can be attained with high accuracy using navigation or fluoroscopy. Yet, the margins for this goal in relation to post-operative pain and patient satisfaction are unresolved and in supine THA intra-operative testing using anatomic and functional measures may suffice.
Hypothesis We asked how accuracy of THA as assessed by changes in leg leg length and offset are related to post-operative pain and patient satisfaction.
Methods Prospective study of 445 supine anterior approach THA on a regular OR table. We quantified the preoperative template and post-operative THA on supine radiographs with patient-specific calibration. Leg length, center of rotation and offset (femoral, acetabular and global offset) were studied separately and in combinations. The outcome measures were lateral (trochanteric) and groin pain (VAS), hip satisfaction (NRS), patient joint perception (PJP), and Oxford hip score. Furthermore a subgroup analysis was performed in the group with the worst outcomes.
Results Complete data were available for 430 hips (97%) at one year. We found no relation between PROMs and reconstruction parameters, irrespective of the outcome measure. At one year, 11 of 15 patients with lowest hip satisfaction (NRS ≤ 6) had trochanteric pain syndrome (TPS), but we found no correlation of TPS with parameters of hip reconstruction.
Conclusion Within the range of accuracy in this study of leg length and hip offset reconstruction in anterior approach THA, we found no relation with overall patient satisfaction, neither for mean values, nor for outliers or subgroups such as TPS. Further improvement in THA may be obtained with better understanding of TPS.

Introduction

While many studies of total hip arthroplasty (THA) suggest a negative influence of changes in leg length and (global) offset, the margins for these changes in relation to patient outcome and satisfaction are uncertain (Appendix 1). For example, study recommendations differ by a factor of four (2,5mm to 10 mm for a single parameter, or 5 mm for the sum of both parameters (Appendix 1).
Supine THA offers additional benefits for cup positioning [10]. Moreover, compared to lateral decubitus THA, in supine THA manipulation of the legs is far easier, allowing more reliable functional testing of the whole hip construct for stability, leg length and soft tissue tension.

Insight in hip reconstruction margins is pertinent to the growing marketing of hip and knee implant positioning systems which, although they can improve accuracy of hip reconstruction, invariably increase cost, often decrease OR efficiency, frequently require additional personnel and / or radiation exposure, yet never come with well-defined margins for hip reconstruction. Convincing evidence for the effect hip positioning systems on post-operative pain and patient satisfaction is not available yet. Alternatively, we may not be using the right surrogate tests (radiographs), nor asking the right questions to detect subtle improvements in patient satisfaction and hip function.

In parallel with cost, patient satisfaction, i.e. the patient's perception of THA outcome is increasingly recognised as an important metric of value based health care [22]. However, PROMs commonly used for THA such as the Oxford Hip score (OHS, [7] or the Hip Osteoarthritis Outcome score (HOOS, [21] have well-known ceiling effects [14] and whether they have the sensitivity to capture more subtle differences after hip joint reconstruction can be questioned. Yet, they are often required by implant registries.
Pain consistently has the highest correlation with patient satisfaction [12], but to improve THA we also have to know the location of pain. Both the OHS and HOOS question only 'overall' hip pain ('pain in or around your hip'), which may cloud the detection of iliopsoas or trochanteric pain syndrome (TPS). Furthermore, these scores ask about functional limitations ('getting in and out of a bus') or symptoms ('morning stiffness'), but do not question the patient's awareness of the joint. Considering the accuracy of hip joint reconstruction this may be a relevant question. 'How does your hip feel' is the key question of the Patient Joint Perception Score (PJP), for which the best answer is 'like a native of natural joint' [26].

In this study we asked whether the accuracy of supine THA as assessed by leg length and hip offset is related to post-operative pain and patient satisfaction. Accuracy was quantified by change in global offset and leg length compared to the pre-operative templating plan. In a further analysis of patients with post-operative pain and / or low satisfaction we also analyzed femoral and medial offset and their ratio as the abductor ratio.

Methods

This is a prospective study of THA using the anterior approach on a standard operating table without fluoroscopy. Preoperative THA templating aims were compared with post-operative implant position using supine, standardized, calibrated anteroposterior pelvic radiographs and a digital templating program (Traumacad, Brainlab, München). Post-operative radiographs were made two weeks after THA.
Primary measures for hip reconstruction were leg length, center of rotation and offset parameters. Leg length and global offset were also examined in a combined measure.
Femoral and medial offset (the moment arm of body weight) were examined as the abductor ratio.
Patient satisfaction was assessed with a subjective numeric rating scale, visual analog pain scores for lateral (trochanteric) and groin pain, the Patient Joint Perception (PJP) score and the Oxford hip score (OHS).

Patients
We examined a prospective cohort of 494 primary THA, operated between 1- 1 -2021 and 1-9-2022 by one surgeon in an orthopaedic treatment center. This setting influenced the constitution of the patient cohort: patient exclusion criteria were age > 80 years, BMI > 35, ASA III or higher classification, or any other anaesthesiological contraindication such as a pacemaker or automatic defibrillator. Inclusion criteria were unilateral or bilateral hip osteoarthritis. Other than these (anaesthesiological) exclusion criteria the patient population was non-selected, including post-epifysiolysis, post-Perthes, post-traumatic, dysplastic, protrusio, post-arthroscopy, post-pelvic osteotomy, rheumatoid and osteonecrosis hips. Of the 494 hips, 64 hips were excluded for reasons shown in Figure 1.

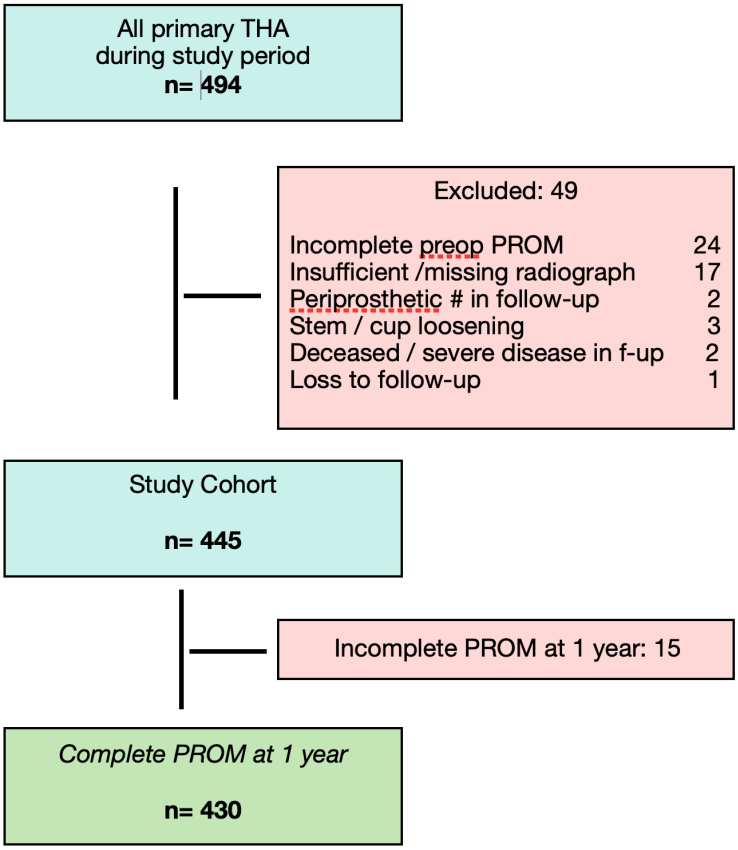


Figure 1: consort diagram of study population

Thus, 430 hips (402 patients, 63% women) had complete PROM data at 1 year follow-up. Of these 430 hips, 417 had complete OHS data pre-operatively and 378 also had complete data of all PROMs at 2 months follow-up. We found no statistically significant differences in 1 year PROMs between the 378 hips with both 2 month and one year data and the 51 hips with only one year data.

Preoperative Radiographs

Preoperatively, supine anteroposterior pelvic radiographs were made with standardized patient positioning. The patient was asked to position her legs in neutral ab- or adduction, with the toes pointing together. Focus film distance was 110 cm. A 36 mm calibration ball was placed under the pubic bone. Four balls on posts of differing height were available for this purpose, so that the ball could be positioned at the presumed level of the hip joint relative to the patient positioning table. For the supine radiograph at two weeks post-operative the same patient positioning and the same post height for the calibration ball were used.

Two observers performed validation measurements to examine test - re-test variation of patient positioning, and of intra- and inter-observer variation of radiographic measurements (JB and TH, Table 2.)

Templating aims. Templating aimed to either restore anatomy, correcting the deformity that developed with osteoarthritis, for example a decrease in leg length or lateralization of the femur. Alternatively, templating aimed to improve hip biomechanics, for example by medializing the cup in dysplastic hips (decreasing acetabular offset), while increasing femoral offset.

When a leg length difference (LLD) was noted on supine examination, the patient was asked whether she noticed a difference in leg length and which leg felt longer. When the patient was unaware of the LLD we discussed keeping the LLD the same or within a few mm. When she was aware of a LLD we discussed options to equalize leg length. Typically, femoral offset was planned to decrease for lengthening and increase for shortening.

Templating

With Traumacad software (Brainlab, München), the AP pelvic image was first calibrated with the 36-mm ball. First, the cup diameter was chosen, usually 4 mm larger than the femoral head diameter. Cup depth relative to the acetabular fossa was templated so that native acetabular offset was restored, or decreased in dysplasia hips. Next, stem type, stem position and femoral head size were chosen. Traumacad displays the planned changes in global offset and leg length in the template (Fig. 2). For hips without (post-traumatic) offset-loss or shortening, the change in the sum of global offset and leg length was planned within approximately 5 mm. Patient height was also considered, with a smaller margin in shorter patients, and a larger one in tall patients.

Template Measurements

The pre-operative template is quantified in Traumacad using the menu option *Measurement - Hip Outcome - Post op.* A simple wizard helps to position 17 points in the template. The basis for measurement is the inter-teardrop line. The 17 points quantify the template with 6 parameters shown in a table. Three of these parameters are referenced off the center of rotation of the planned acetabular cup (femoral offset, medial offset and ilio-ischial (acetabular) offset) and two are referenced off the inter-teardrop line (center of rotation and hip height). The sixth parameter is stem alignment, relative to the femoral diaphysis. The global offset is the sum of the acetabular and femoral offset. Leg length (hip height in Traumacad) is quantified as the position of the lesser trochanter or the tip of the greater trochanter relative to the inter-teardrop line. When the inter teardrop line can

not be used, the most distal margins of both ischia can be used, or the most proximal margins of the obturator foramina.

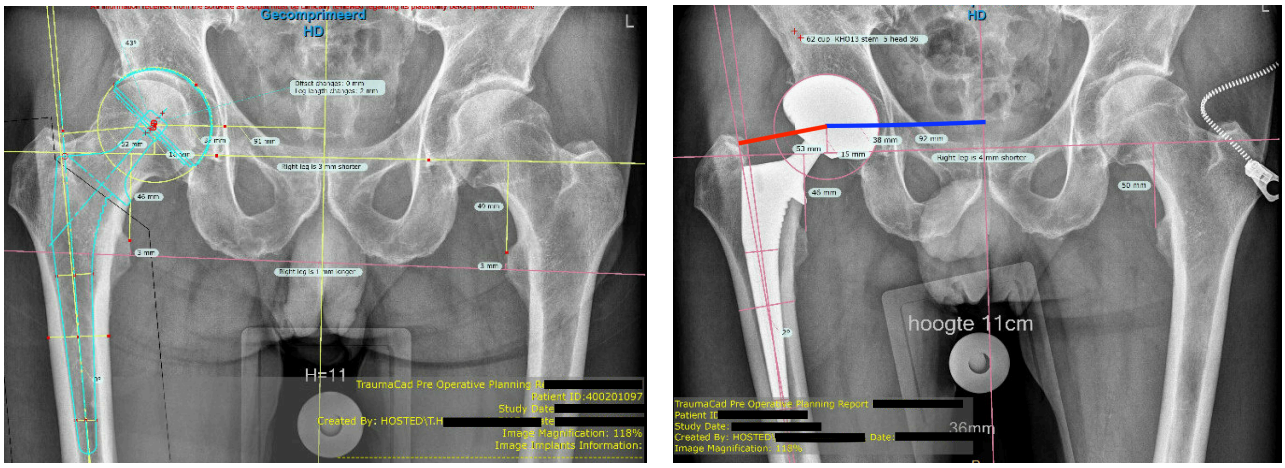


Figure 2: measurements with templating software pre- and post-operative on supine radiographs with same height of calibration post. Abductor ratio is the moment arm of bodyweight (blue line, "medial offset" in Traumacad) divided by the moment arm of the hip abductors (red line, "femoral offset" in Traumacad).

Radiographic exclusion criteria
Missing or insufficient radiographs (variation in positioning with abduction / adduction or internal / external hip rotation which influenced measurements) and use of a different format radiograph were exclusion criteria (Fig. 1). Rotation was assessed using the contours of the greater [1] and lesser trochanter [13].

Clinical exclusion criteria
Incomplete questionnaires (inability to fill out, no-show / not reachable for follow-up, deceased or disease that limited daily activities, signs of stem or cup loosening, post-operative peri-prosthetic fracture not-related to surgery were exclusion criteria (Fig. 1).

Total hip arthroplasty was performed using the anterior approach (supine) on a standard operating table without fluoroscopy or navigation. A capsulotomy was performed from the anterolateral acetabular rim to the calcar femorale, preserving the medial part of the iliofemoral ligament that can be used in determining leg length and soft-tissue tension [20]. A (cranial) capsular flap was created by releasing the capsule from the inside of the greater trochanter. This flap was excised in most hips. It was repaired only when the capsule thickening was limited and in most dysplastic hips. Femoral release started at the calcar femorale, if needed, with the leg in a figure of four position. The capsule on the inner surface of the greater trochanter was released in all cases, followed if needed by release of the conjoined tendon. The piriformis and obturator externus tendons were not released [9].
Acetabular reaming was based on the Traumacad template for size, but also for depth, i.e cup position relative to the acetabular fossa. Cup size was usually the femoral head diameter + 4 mm. Cup position was based on the transverse acetabular ligament for depth, anteversion and inclination. Depth of the cup was adjusted if needed, after palpation of the anterior acetabular labrum or its osteophytes, to prevent iliopsoas tendon impingement by a protruding cup edge. This could mean reaming deeper than templated,

for example in hips with anterior acetabular wall dysplasia. Loss of acetabular offset in these hips was compensated with increasing femoral offset.

Femoral preparation was done with the femur in adduction under the contralateral leg, hyperextension of the operating table was rarely used. Stem position was determined according to the femur's natural anteversion and relative to the obturator externus tendon or lateral femoral neck remnant for height. Leg length was assessed at the heels and knees, stability was tested for posterior and anterior dislocation, soft tissue tension was tested in distal and lateral direction. In a supine patient with the hip in neutral position, the medial arm of the iliofemoral ligament, when intact, allows at most 1 mm of distal femoral head translation from the acetabulum with longitudinal traction when leg length is correct. This translation increases to approximately 3 - 4mm with 30 degrees of hip flexion upon relaxation of the iliofemoral ligament. Similar testing was used in lateral direction to assess offset tension. Spinal anesthesia was used in 90% of cases, affording a reproducible level of muscle relaxation for testing of soft tissue tension of the hip construct. In patients with general anesthesia muscle relaxant was used for the same purpose.
Implants used were a hemispherical cup in all patients (Pinnacle, DePuy Synthes, 115 with polyethylene and 315 with ceramic inserts) and two stem designs, a medium length curved triple taper stem (Fitmore, Zimmer Biomet n = 57) and a fully HA coated collared stem (Corail, DePuy Synthes, n = 373).

Post-operative radiographs were made at two weeks with the same positioning protocol and the same calibration ball as pre-operative. The same measurements were performed, only now of the actual hip implant, using the menu option Measurement - Hip Outcome - Post op in Traumacad (Fig. 2).

Intra-observer and inter-observer correlation coefficients for pre-operative template and post-operative implant position were measured on 20 hips (All ≥ 0.90, Table 2.)
Test-re-test of patient positioning was done with 14 patients who had a repeat AP pelvic radiograph several hours or days after the first radiograph. On both radiographs one observer measured hip height and global offset of the pre-operative hip (without implant template).

	Inter-observer	Intra-observer Observer 1	Intra-observer Observer 2	Test re-test
Hip height preop	0.94	0.94	0.95	0.99
Global offset preop	0.93	0.93	0.99	0.98
Hip height postop	0.94	0.94	0.90	NA
Global offset postop	0.94	0.94	0.97	NA

Table 1: Correlation coefficients for pre-operative template and post-operative implant (repeated) measurements on 20 patients.

Reporting of accuracy of hip reconstruction
Global offset change (GOC) and leg length change (LLC) were used as explanatory variables. GOC and LLC were combined as a measure for accuracy, not just as their algebraic sum, but also as the (Pythagorean) distance to the 45 degree line that represents their balance (Figure 3).
This measure also accounts for the direction of change, in a formula this is: LLC (in comparison to plan) = - GOC (in comparison to plan). We termed this measure distance to balance line, or DBL (Figure 3).

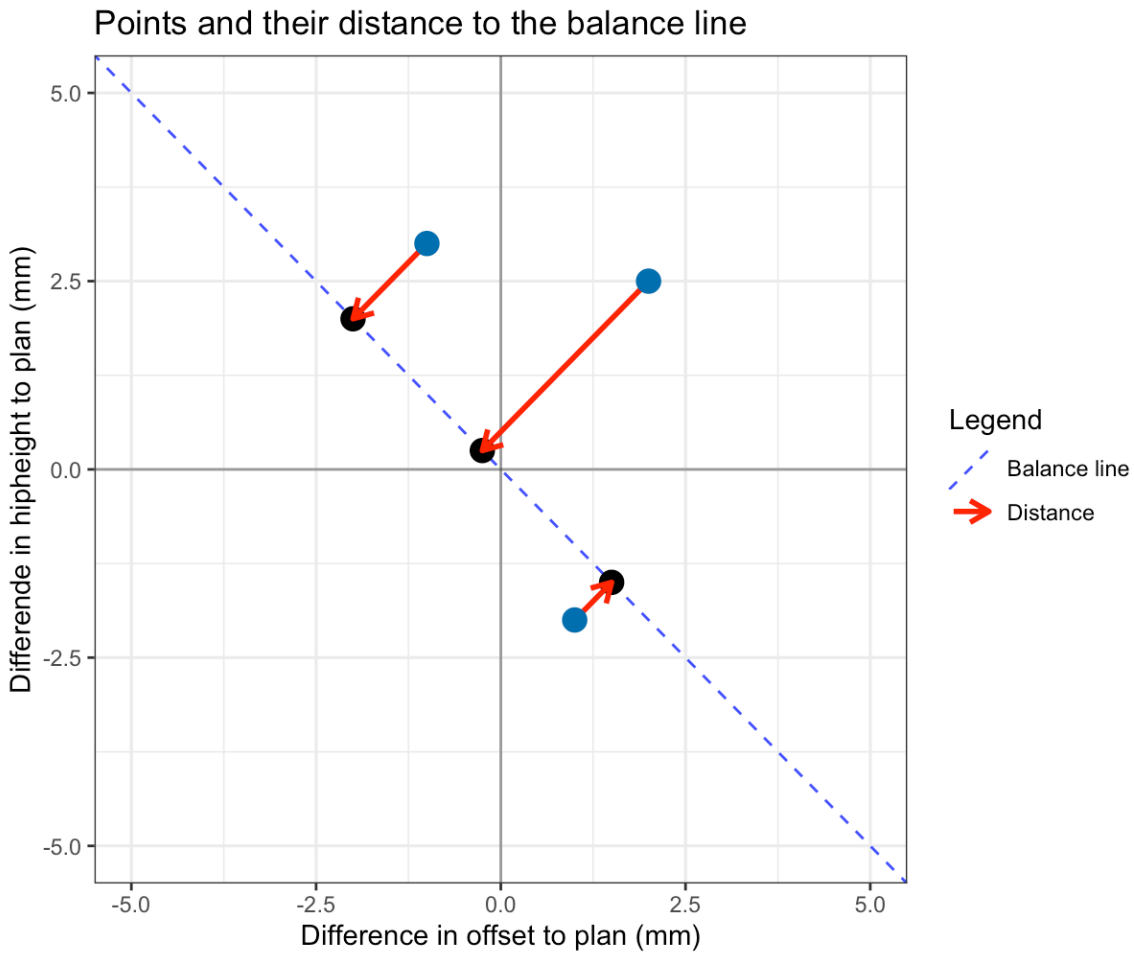


Figure 3: Four quadrants with combined global offset and leg length change and the 45 degree balance line. Distance to balance line (DBL) is shown in red. DBL is calculated as: dist_to_line_plan = (offset_difplan + Leglength_difplan) / sqrt(2)

Results were analyzed in three groups based on the (arbitrary) threshold of + / - 5 mm within the templated change. In addition, we analyzed whether correction for body height influenced results. The height range was 152 - 207 cm, median height was 172 cm. We found no difference in our results when corrected for body height and these results are therefore not shown.

Patient reported outcome was determined pre-operatively and post-operatively at two months and one year.

The Oxford Hip Score (OHS [7]) and Patient Joint Perception score [26] were used, the latter was adapted to also allow preoperative use (Appendix 1). The PJP question aims to identify patients with successful surgery and a forgotten joint, but in patients with suboptimal results it does not determine causes for dissatisfaction or dysfunction. Therefore specific questions for lateral and groin pain post-operatively were added with a visual analog scale (VAS) of 0 - 10 (Appendix 1). Satisfaction was determined with a numeric rating scale (NRS) with the question “On a scale of 0 to 10, how do rate your hip” (Appendix 1). Fulfillment of patient expectations was assessed with the question "were your expectations fulfilled, yes / no, if no why not"?

Follow-up was by email and telephone, but clinic visits were scheduled when patients were not happy with their rehabilitation. During follow-up visits imaging and clinical tests were performed to determine the cause of low satisfaction and / or pain. Iliopsoas pain was assessed with active hip flexion when sitting. Trochanteric pain syndrome (TPS) was defined as lateral hip pain of VAS 4 or higher and positive clinical symptoms and tests. Symptoms were lateral hip pain with walking and pain at night when lying on the side. Clinical test were the cycle test in lateral decubitus and with resisted internal hip rotation in supine postion [17]. In the cycle test the patient lies on his non-affected side and makes a cycling movement with the affected leg in the horizontal plane. Both tests are considered positive when the patient recognizes her trochanteric pain.

At one year follow-up, two subgroups were defined of patients with low NRS-satisfaction (NRS ≤ 6) and / or TPS.
To study the further evolution of TPS in time, this subgroup was assessed once more with additional follow-up longer than two years (range 28 - 44 months).

Statistical analysis
Descriptive analysis was used to describe patient characteristics at baseline in total, for all groups of accuracy and between the best/worst scoring patient groups. The Generalized Estimation Equation (GEE) method was used for estimating the effects of accuracy on the outcome measure for different points over time. The GEE method is a quasi-likelihood method, used for repeated measures. This method corrects for within subject correlation in time repeated measures and includes the outcome measure of all time points, i.e. two months and one year. Baseline data is necessary for using GEE, but the advantage is that data of patients in which some measurements are missing can be included and analyzed. Patient characteristics (gender, age and baseline measurements) were included to correct for confounding. The explanatory variable for hip accuracy, the distance to the balance line (DBL) was included as an interaction term with time variables. After preliminary analysis, GEE was performed with the outcome variables, NRS-satisfaction and OHS. Analysis was repeated with cut-off groups for hip reconstruction accuracy to estimate the treatment effect for lower or higher than 5 mm hip reconstruction accuracy. All analysis was performed using RStudio version 2024.09.1+394.

Results

Within the range of accuracy of THA of this study, we found no statistically significant association between patient reported outcome and global offset, leg length or their combined change. This was found regardless of whether changes in offset and leg length were analysed in isolation or combination, nor when corrected for body height (Fig. 4, 5, Table 2). The only exception was groin pain which was statistically significantly higher at $p = 0.032$ in the 20 patients with > 5 mm increase in distance to balance line (DBL, Table 2).

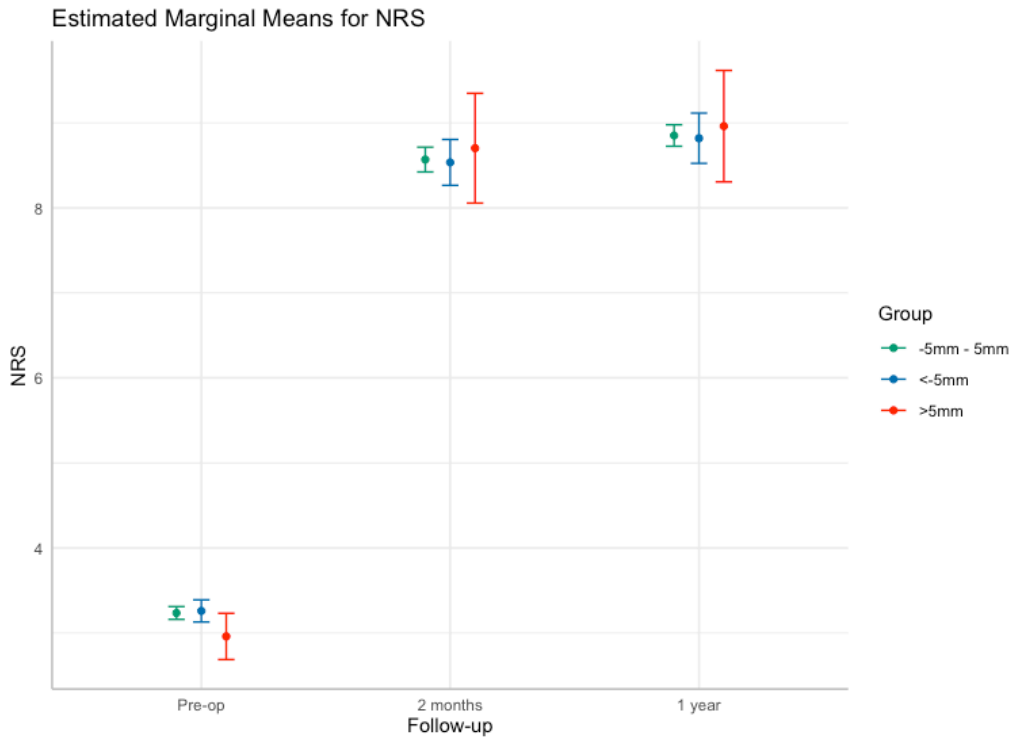
At one year, hips with the most accurate reconstruction did not differ in a clinically significant way in any PROM from groups with either decreased or increased DBL, nor did the latter two groups differ from each other (Table 2, and Appendix: Table 4, 5).

Descriptive statistics

Mean leg length difference between pre and post-operative was -0.25mm, global offset difference 1.25mm and total distance difference 1.25mm. Difference between pre- and post-operative leg length was within 10mm in 98% of hips, within 5mm in 78% of hips. Difference between pre- and post-operative global offset was within 10mm in 97% of hips, within 5mm in 77% of patients. Regarding Leg length, we found more shortening than lengthening, with one outlier of 14 mm shortening in a patient with a subsided collarless stem (this patient had NRS-satisfaction of 10 and OHS of 48 points at one year).

Overall, hip reconstruction was slightly skewed to a decrease in global offset and leg length compared to the template plan (Fig. 6).

Patient expectations were fulfilled in 91 % at two months, this percentage remained the same at one year. Pain was the most frequent cause mentioned for unfulfilled expectations (46%).



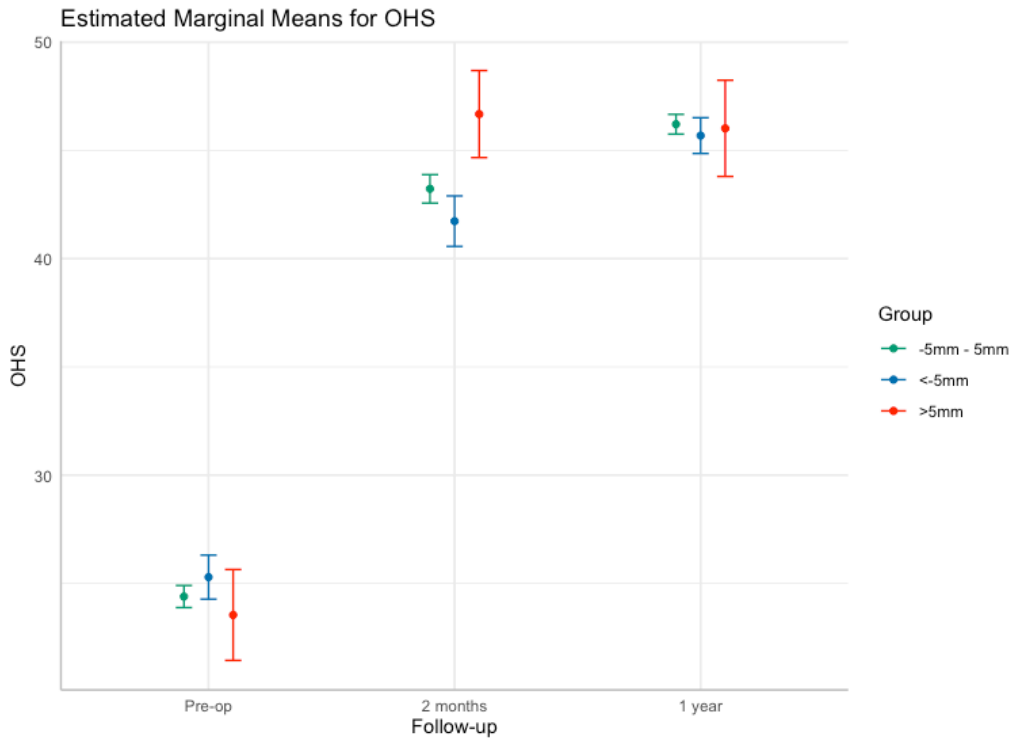


Figure 4: GEE with NRS (n = 429) as the outcome measure.
Figure 5: GEE with OHS (n = 414) as the outcome measure.

Estimated marginal means with the confidence intervals are shown at T= 0, 2 months and 1 year follow-up. Figure 5 indicates a slight difference at 2 months follow-up, but there is

no difference at 1 year. Groups are shown within 5 mm of the templated goal (green), more than 5 mm decrease and more than 5 mm increase from the templated goal (red).

Variable	-5mm - 5mm (N=333)	<-5mm (N=77)	>5mm (N=20)	p value
Age	65.6 (8.7)	62.5 (10.5)	61.8 (12.6)	0.009
Gender (F)	225 (68%)	32 (42%)	17 (85%)	< 0.001
BMI	26.5 (14.2)	26.9 (3.2)	26.6 (3.5)	0.971
Height (cm)	173.2 (9.285)	176.9 (8.8)	172.1 (9.1)	0.006
Difference in total distance to plan	5.1 (2.8)	9.1 (2.6)	9.2 (4.2)	< 0.001
Change in leg length to plan	-1.7 (4.0)	-6.1 (4.0)	1.5 (4.5)	< 0.001
Change in total offset to plan	0.9 (3.9)	-4.8 (3.9)	8.0 (4.2)	< 0.001
DBL	-0.5 (2.8)	-7.7 (2.0)	6.7 (1.2)	< 0.001
Baseline OHS	24.2 (7.5)	25.8 (7.1)	22.7 (7.7)	0.168
OHS Missing	12	3	1	
OHS at 1 year	46.0 (3.3)	46.2 (2.6)	45.1 (4.0)	0.370
Baseline NRS	3.2 (1.1)	3.3 (1.0)	2.7 (1.0)	0.108
NRS Missing	1	0	0	
NRS at 1 year	8.8 (1.1)	8.8 (1.2)	8.7 (1.4)	0.884
Baseline PJP	3.5 (0.6)	3.5 (0.6)	3.8 (0.6)	0.168
PJP at 1 year	1.4 (0.7)	1.4 (0.7)	1.4 (0.7)	0.975
Groin pain at 1 year (0-10)	0.4 (1.1)	0.4 (1.0)	1.1 (2.0)	0.032
Lateral pain at 1 year (0-10)	0.6 (1.3)	0.6 (1.2)	0.9 (1.7)	0.723

Table 2: The group with the most accurate reconstruction (-5mm to + 5mm, n = 333) did not differ in PROMs from the other two groups, neither did these other groups differ from each other, with the only exception of more groin pain in the group > 5mm.

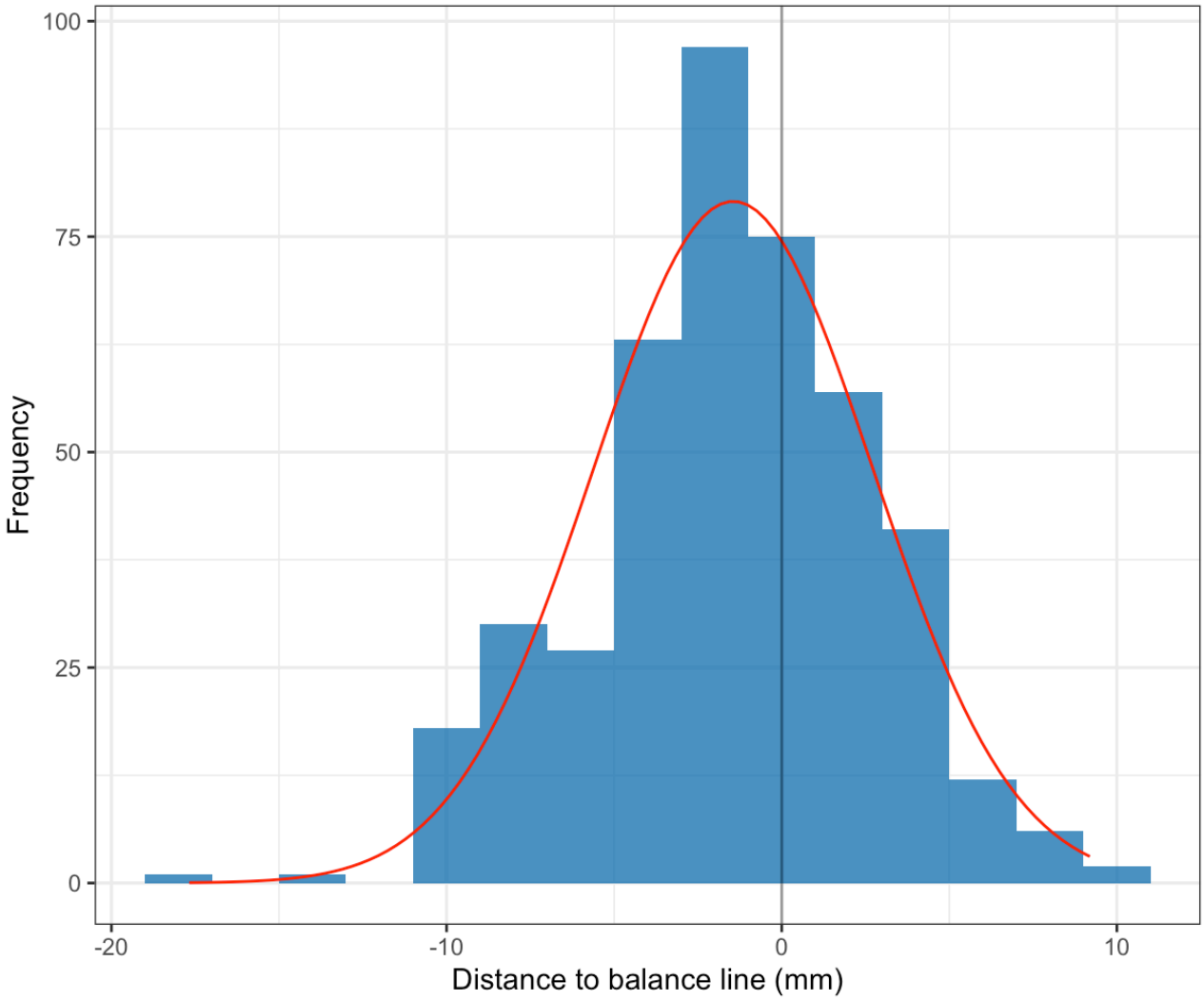


Figure 6: Histogram of distance to balance line on post-operative radiographs

Subgroups: low satisfaction and trochanteric pain syndrome (TPS)

Low Satisfaction
At one year post-operative, 15 patients (15 hips (3%), 13 women) rated satisfaction with their hip NRS 6 or lower, on a scale of 0 - 10. Eleven of these patients (73%, all women) had trochanteric pain syndrome (TPS), with lateral hip pain on VAS ≥ 4 during walking and / or at night. Other patients rated their hip NRS ≤ 6 at one year due to complications, i.e. persistent neuropathy of the lateral cutaneous nerve of the thigh (1), persistent stiffness of the hip (1), or gave a low rating after dislocation (1). One patient did not specify reasons for dissatisfaction.

Trochanteric Pain Syndrome (TPS)
At one year post-operative, 19 patients reported lateral pain of VAS 4 or higher (19 hips, (4%), 90% women, this group includes the 11 patients with NRS ≤ 6 mentioned above).
In 5 TPS patients MRI was made at one year; the indication for this was most often a poorly executed cycle test. No abnormalities other than tendinosis and some bursal fluid were seen; abductor tendon tears were not found.
We compared the 19 TPS patients to 190 patients that had optimal outcome, defined as a forgotten joint (PJP 1), NRS of 9 or 10, no pain (VAS 0 for lateral and groin), and OHS 47

or 48 points at 1 year follow-up. We found no difference between the two groups in global offset and leg length or their combination as DBL (Table 3, Fig. 7).

Variable	Average (N=221)	Best hips (N=190)	TPS hips (N=19)	p value
Age	64.6 (9.2)	65.2 (9.5)	64.5 (9.2)	0.803
Gender (F)	144 (65%)	113 (60%)	17 (90%)	0.028
Difference in TD to plan (mm)	6.3 (3.3)	5.9 (3.3)	4.7 (2.2)	0.107
Change in leg length to plan	-2.7 (4.5)	-1.9 (4.4)	-2.4 (3.6)	0.181
Change in total offset to plan	0.5 (4.8)	-0.1 (4.8)	0.3 (2.9)	0.404
DBL	-1.5 (4.1)	-1.4 (4.3)	-1.5 (3.7)	0.959
Baseline OHS *Missing*	24.9 (6.8) *N=9*	24.0 (7.9) *N=7*	21.8 (8.7) *N=0*	0.145
OHS at 1 year	45.3 (2.5)	47.8 (0.4)	36.0 (5.6)	< 0.001
Baseline NRS *Missing*	3.2 (1.1) *N=0*	3.2 (1.1) *N=1*	2.8 (1.1) *N=0*	0.343
NRS at 1 year	8.4 (0.9)	9.6 (0.5)	6.0 (1.5)	< 0.001
Baseline PJP	3.5 (0.6)	3.6 (0.6)	3.5 (0.6)	0.947
PJP at 1 year	1.6 (0.8)	1.0 (0.0)	2.5 (0.9)	< 0.001
Groin pain at 1 yr 0-10	0.7 (1.1)	0.0 (0.0)	2.6 (2.7)	< 0.001
Lateral pain at 1 yr 0-10	0.8 (1.0)	0.0 (0.0)	5.2 (1.2)	< 0.001
Accuracy group				0.720
-5mm - 5mm	174 (79%)	145 (76%)	14 (74%)	
<-5mm	37 (17%)	37 (20%)	3 (16%)	
>5mm	10 (5%)	8 (4%)	2 (11%)	

Table 3: descriptives for trochanter pain syndrome (TPS). TD is total distance, DBL distance to balance line.

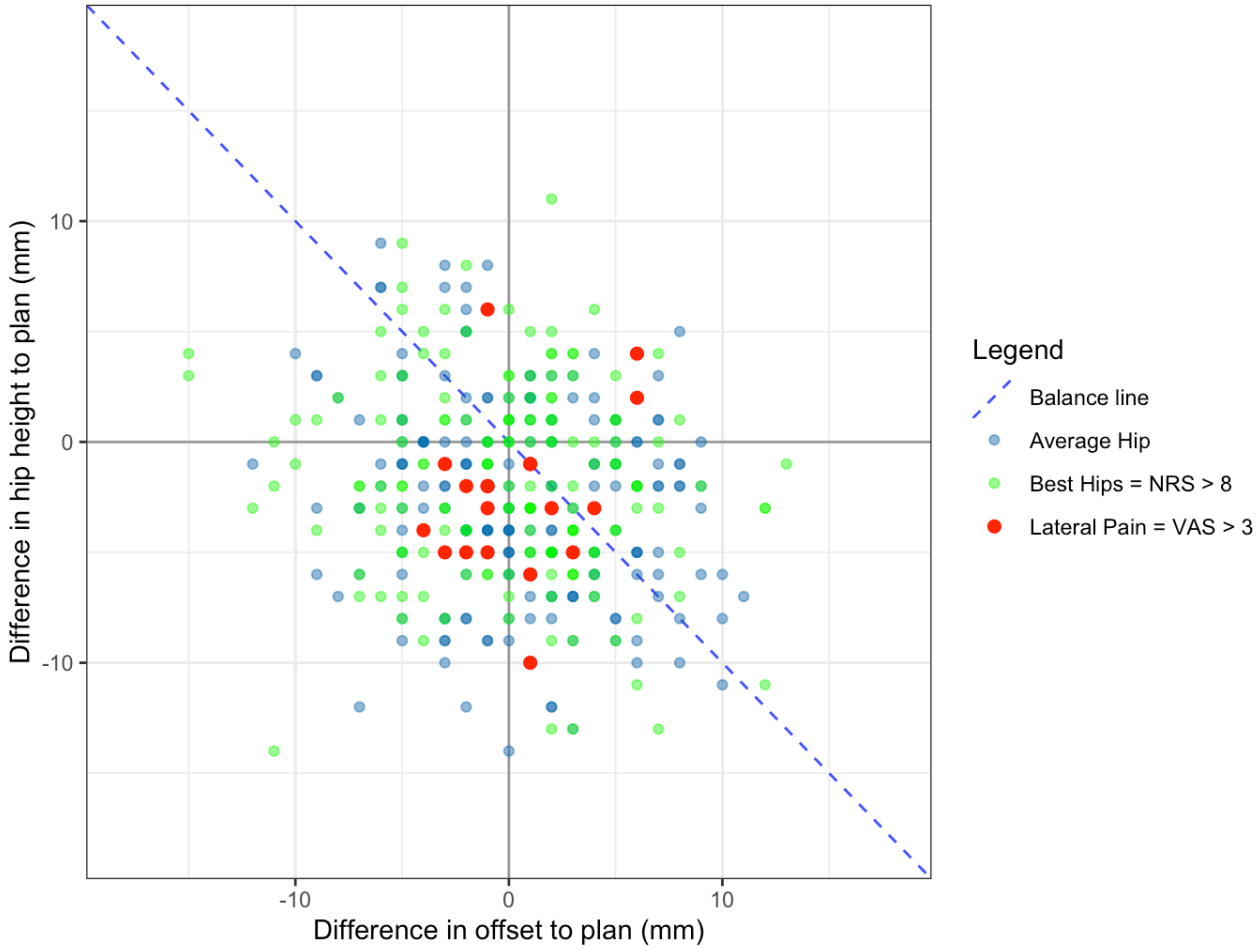


Figure 7. Change in global offset (GOC) and leg length (LLC) in comparison to the template (plan) in patients with optimal outcome and those with lateral pain of > 3 at one year follow-up.

All 19 hips with TPS were contacted again after more than two year follow-up (range 28 - 44 months). Seven of the 19 TPS patients (37%) were considerably improved (NRS ≥ 8 and lateral pain ≤ 2) while 12 of 19 reported minor or no change.
With the numbers available, we did not find statistically significant differences between TPS patients that improved and those that did not, except for the preoperative NRS scores which were lower pre-op for patients that did not improve (3.4 vs 2.5, respectively, $P = 0.04$, preoperative NRS was 3.2 in the 190 hips with optimal outcome). OHS also tended to be lower pre-operative, but this was not statistically significant (26 vs 19, $P = 0.06$, preoperative OHS was 24 in the 190 hips with optimal outcome).
MRI was done or repeated (n=1) in 5 of the 12 patients that did not improve. In three of these hips MRI was normal. One patient had had ipsilateral pubis fracture in the further follow-up period, one patient had some fluid around the gluteus medius insertion, but more so on the contralateral (better functioning) hip where signs of tendinopathy were also present.

In addition, we compared change in abductor ratio between hips with best outcome and those with TPS, but found no explanation for differences in lateral pain (Fig. 8).

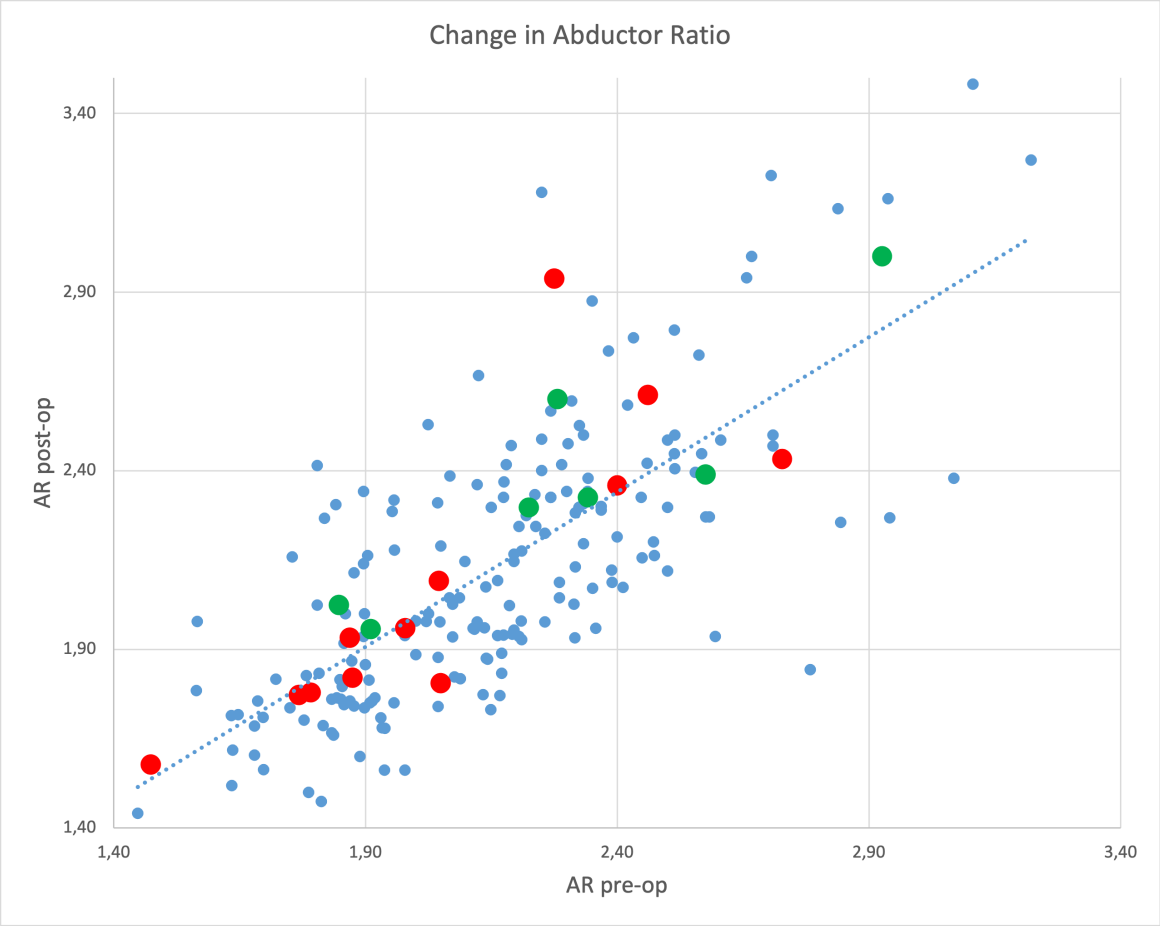


Figure 8: pre- and post-operative abductor ratio (AR) depicted for 190 hips with best outcome (blue) and 19 hips with TPS at one year. At 28 - 44 months follow-up, TPS hips that improved (green dots) were not different from those that did not (red dots).

Discussion

In a prospective study of 430 consecutive patients, we found no relation between the accuracy of supine THA and patient reported outcome, neither for mean values, nor for outliers or subgroups. The only exception was groin pain which was statistically significantly higher at $p = 0.032$ in the 20 patients with > 5 mm increase in distance to balance line (DBL). This may indicate iliopsoas pain, but we are not sure whether this is clinically relevant given the low level of pain (mean VAS 1.1; only 3 / 20 patients had groin pain VAS ≥ 4) and the small difference with the other two groups (0.7, i.e. less than half the minimal detectable change in VAS - pain [6].

Lateral pain was more relevant to patient satisfaction due to both its higher intensity and prevalence. At one year post-operative trochanteric pain syndrome (TPS) was the most frequent reason for low patient satisfaction. But compared to patients with optimal outcome, TPS patients did not differ in changes in global offset, leg length, their combination, or the abductor ratio, a measure related to abductor muscle work with walking.

Other studies have linked TPS to low PROMs after THA and did suggest a correlation to global offset and leg length. Three years after anterolateral approach THA, Worlicek et al reported TPS in 21 / 90 patients (23%) and suggested summed change of global offset and leg length should be within 5 mm [29]. TPS was associated to a poorer clinical outcome, as we found, but further comparison is difficult because, for example, Worlicek et al state that pre-operatively none of their patients had symptoms of TPS, defined in their study as tenderness on palpation of the greater trochanter and painful active abduction of the hip. We find however that, pre-operatively, a large majority (85%) of our osteoarthritis patients report lateral hip pain of VAS ≥ 4 (see below). Another study on TPS after anterolateral THA by Hirano et al suggested a range comparable to that of Worlicek, but only for global offset. Leg length data were not summed and TPS or lateral pain were not defined [15].

Nevertheless, we also expected to find a relation between accuracy of THA and patient reported outcome, manifesting itself in pain and / or symptoms such as TPS. We assume biomechanical parameters play a role in such symptoms, for example through the ratio of moment arms of bodyweight and abductors (abductor ratio). Women have a higher abductor ratio than men, an expression of pelvic sexual dimorphism [8, 28] and a cause for higher abductor muscle loading [23].

At more than two years follow-up, over one third of TPS patients in our study were considerably improved, while two thirds were unchanged, which in this study would be 3% of patients.

Conversely, TPS has a high prevalence in the general population, especially women. The TPS group in our study included 90% women. TPS is four times more prevalent in women than men in general practice [18] and may affect 1 in 4 women older than 50 years [5]. Characteristically, women of this age group constitute 60-65% of THA patients. Indeed, joint and muscle pain are some of the most common symptoms of menopause, and there is increasingly compelling evidence that changes in or loss of sex hormones influence musculoskeletal pain propensity and perhaps disease [11].

Trochanteric pain is more frequent after posterolateral than anterior THA [19], but even without a scar over the trochanter, patients may still perceive that trochanteric pain is related to the hip replacement surgery. Within the range of accuracy of our study, we found no biomechanical explanation nor explanatory MRI findings for TPS. In our view, this supports interpretation of TPS as age and sex hormone related mucoid degeneration of the abductor tendons [3].

Although not related to patient reported outcome, we did find the three groups of accuracy (defined as distance to balance line (DBL) within 5 mm of the templated goal, more than 5 mm decrease and more than 5 mm increase) differed with regard to gender, age and height. The group with more than 5 mm decrease was 58% male, the group with more than 5 mm increase was 85% female. Our interpretation of these findings is that in male hips it may be more difficult to attain the intended leg length and offset due to adhesions and stiffness of the thickened medial part of the iliofemoral ligament, as compared to female hips. We have since increased our femoral release with detachment in figure of four position of the calcar adhesions of the pubofemoral and iliofemoral ligament.

Study Limitations

Our study has limitations inherent to the methods chosen: we used only AP pelvic radiographs (coronal plane), and did not use 3D-templating or CT scans for follow-up. Hence we have no data on several parameters of hip reconstruction, for example cup or stem anteversion or the restoration of the acetabulum in the sagittal plane. We assume however that, given the importance of hip abductor and iliopsoas function for normal gait and daily activities, offset and leg length abnormalities would create patient dissatisfaction more readily than other, more subtle parameters of hip reconstruction.

Patients all had BMI < 35 and ASA < 3, a consequence of the anaesthesiological exclusion criteria at our clinic. We acknowledge component positioning and clinical tests, for example for leg length, may be more difficult in the morbidly obese. Similarly, as patients with more comorbidities, and therefore higher ASA grade, may have higher post-operative pain [30], our findings may not be generalizable for all THA patients.

At the 2 month follow-up we had a lower response rate. At this time point data collection was done without follow-up for missing data. At the one year follow-up patients were contacted, repeatedly if necessary, by mail or telephone which resulted in the higher response rate at one year. However, we found no difference in one year follow-up PROMs between the patients that had both 2 month and 1 year follow-up, compared to those who had only one year follow-up data.

We realize that femoral offset and medial offset do not represent the true moment arms of the abductors and bodyweight [16]. Nevertheless, our measurements capture the changes in these moment arms using an identical method pre- and post-operatively and are therefore useful to detect a change in ratios.

We did not assess groin and lateral hip pain systematically before operation. Based on our findings of TPS post-operatively (and a lower OHS in these patients pre-operatively), we now asses lateral hip pain routinely before THA and find no statistically significant difference with groin pain in either severity or frequency (VAS 5.9 mean lateral pain, 6.0 groin pain ($p = 0.3$); lateral pain ≥ 4 in 85%, groin pain ≥ 4 in 82%; $n = 531$, unpublished data). Post-operatively, lateral hip pain persists more frequently and more severely than groin pain, while at the same time lateral pain at one year correlates higher with NRS-satisfaction ($r = 0.66$) than groin pain ($r = 0.44$).

We did not assess psychological aspects in this study such as pain catastrophizing, anxiety or depression, which are not infrequent in arthroplasty and TPS patients [6, 24], and this may have negatively skewed our findings in some patients with low satisfaction and high pain scores.

Lastly, the validity and reliability of self-report measures such as PJP and NRS can be questioned [2, 27]. Their nature as patient reported outcomes may affect the internal validity of the study. We combined these measures with VAS scores for groin and lateral

hip pain and the OHS. Nonetheless, even the combination of these PROMs was not without ceiling effects for the 2 month and 1 year follow-up.

Study Strengths

We report on a large prospective cohort operated with standardized technique by a single surgeon. This cohort is unselected other than for anaesthesiological ciriteria. We examined the change of global offset and leg length, also with attention to patient height. In conjunction with traditional PROMs, additional assessment with NRS subjective rating, PJP and questions specifying lateral and groin pain provided new information as to the causes of poorer outcome and allowed us to focus on patients with the lowest satisfaction and most pain. We examined outliers by comparing patients with lowest and highest satisfaction, and by comparing most accurate with least accurate reconstructions. The ipsilateral hip was used as reference and not the contralateral hip (which may differ in offset or leg length and have osteoarthritic changes in over 30% [4]. Response rate at one year follow-up was 97% for the study cohort, which is important for THA evaluation [25].

Conclusion

Within the range of accuracy of leg length and hip offset reconstruction in supine THA, we found no relation with overall patient satisfaction, neither for mean values, nor for outliers or subgroups such as TPS. Further improvement in THA may be obtained with better understanding of TPS.

Appendix 2

PROMs pre-operative

NRS-satisfaction: How do you rate your hip from 0 - 10:

0 Disastrous, it could not be any worse
1
2
3
4
5 Not Good, Not Bad
6
7
8
9
10 Excellent, it could not be better

PJP:* "*How do you perceive your hip?"

1: like a discomfort with no restrictions
2: like a painful joint with no restrictions
3: like a painful joint with minimal restrictions
4: like a painful joint with major restrictions
5: like a painful, non-functioning joint

PROMs post-operative

NRS-satisfaction: How do you rate your hip from 0 - 10:

0 Disastrous, it could not be any worse
1
2
3
4
5 Not Good, Not Bad
6
7
8
9
10 Excellent, it could not be better

PJP:* "*How do you perceive your hip?"
1: like a native or natural joint
2: like an artificial joint with no restriction
3: like an artificial joint with minimal restriction
4: like an artificial joint with major restriction
5: like a non-functional joint

How much pain did you experience in your hip (operated side) during the last week?

On the outside

0 1 2 3 4 5 6 7 8 9 10
Painfree ***Unbearable***

In the groin

0 1 2 3 4 5 6 7 8 9 10
Painfree ***Unbearable***

Table 4: gee_ohs_totdist_grp-1

	term	estimate	Standard error	statistic	p-value
1	(Intercept)	18,009	3,194	31,799	0,000
2	OHS baseline	0,374	0,019	368,457	0,000
3	Dummy T = 2 months	18,829	0,509	1370,165	0,000
4	Dummy T = 1 year	21,813	0,437	2494,203	0,000
5	Age	-0,007	0,013	0,338	0,561
6	Length	-0,016	0,016	0,938	0,333
7	BMI	0,004	0,005	0,807	0,369
8	Sex = Male	0,601	0,309	3,790	0,052
9	Group < -5mm x Dummy baseline	0,896	0,585	2,341	0,126
10	Group > 5mm x Dummy baseline	-0,851	1,099	0,600	0,439
11	Group < -5mm x Dummy 2 months	-1,493	0,675	4,893	0,027
12	Group > 5mm x Dummy 2 months	3,452	1,078	10,262	0,001
13	Group < -5mm x Dummy 1 year	-0,526	0,477	1,216	0,270
14	Group > 5mm x Dummy 1 year	-0,191	1,157	0,027	0,869

Table 5: gee_nrs_totdist_grp

	term	estimate	Standard error	statistic	p - value
1	(Intercept)	3,192	0,926	11,898	0,001
2	NRS baseline	0,394	0,033	146,089	0,000
3	Dummy T = 2 months	5,332	0,089	3580,213	0,000
4	Dummy T = 1 year	5,614	0,082	4641,011	0,000
5	Age	0,004	0,004	0,816	0,366
6	Length	-0,009	0,005	3,698	0,054
7	BMI	0,002	0,001	5,155	0,023
8	Sex = Male	0,184	0,093	3,947	0,047
9	Group < -5mm x Dummy baseline	0,024	0,078	0,097	0,756
10	Group > 5mm x Dummy baseline	-0,276	0,141	3,799	0,051
11	Group < -5mm x Dummy 2 months	-0,033	0,157	0,045	0,831
12	Group > 5mm x Dummy 2 months	0,134	0,339	0,156	0,693
13	Group < -5mm x Dummy 1 year	-0,032	0,166	0,037	0,847
14	Group > 5mm x Dummy 1 year	0,110	0,341	0,104	0,747

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