MRI Assessment of Muscle Damage After the Posterolateral Versus Direct Anterior Approach for THA (Polada Trial). A Randomized Controlled Trial

Rykov, Kyrill; Meys, Tim W G M; Knobben, Bas A S; Sietsma, Maurits S; Reininga, Inge H F; Ten Have, Bas L E F

Published in:
The Journal of Arthroplasty

DOI:
10.1016/j.arth.2021.05.009

The Journal of Arthroplasty 36 (2021) 3248–3258

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Primary Hip

MRI Assessment of Muscle Damage After the Posterolateral Versus Direct Anterior Approach for THA (Polada Trial). A Randomized Controlled Trial

Kyrill Rykov, MD [a,*], Tim W.G.M. Meys, MD [b], Bas A.S. Knobben, MD, PhD [a], Maurits S. Sietsma, MD [a], Inge H.F. Reininga, PhD [c], Bas L.E.F. ten Have, MD [a]

[a] Department of Orthopaedic Surgery, Martini Hospital Groningen, the Netherlands
[b] Department of Radiology, Martini Hospital Groningen, the Netherlands
[c] Department of Trauma Surgery, University of Groningen, University Medical Center Groningen, the Netherlands

ARTICLE INFO

Article history:
Received 25 March 2021
Received in revised form
26 April 2021
Accepted 7 May 2021
Available online 15 May 2021

Keywords:
direct anterior approach
posterolateral approach
MRI
muscle atrophy
total hip arthroplasty
polada

ABSTRACT

Background: There is controversy in literature whether the direct anterior approach (DAA) results in less muscle damage compared with the posterolateral approach (PLA) for total hip arthroplasty. The aim of this randomized controlled trial was to assess muscle damage between these two approaches.
Methods: Forty-six patients were included. Muscle atrophy, determined with the Goutallier classification, and muscle surface of twelve muscles were analyzed on magnetic resonance imaging images made preoperatively and one year postoperatively. Differences in component placement after DAA or PLA were assessed on radiographs. Harris hip scores and Hip disability and Osteoarthritis and Outcome Score were used as functional outcomes.
Results: External rotator musculature was damaged in both approaches. After PLA, the obturator muscles showed significantly more atrophy and a decrease in muscle surface. After DAA, the tensor fascia latae showed an increased muscle atrophy and the psoas muscle showed a decreased muscle surface. An increase in muscle surface was seen for the rectus femoris, sartorius, and quadratus femoris after both approaches. The muscle surface of the gluteus medius and iliacus was also increased after PLA. No difference in muscle atrophy was found between the approaches for these muscles. The inclination angle of the cup in PLA was significantly higher. No differences were found in functional outcomes.
Conclusion: Different muscle groups were affected in the two approaches. After PLA, the external rotators were more affected, whereas the tensor fascia latae and psoas muscles were more affected after DAA.

Total hip arthroplasty (THA) remains one of the most successful interventions in orthopedic surgery. The demand for THA is increasing worldwide and patients are becoming younger, more active, and demand a faster recovery. To accelerate postoperative recovery several interventions have been introduced over the last decades, such as fast-track recovery protocols and minimal invasive THA [1–3]. The proposed benefits of these minimal invasive techniques are a decrease in muscle damage, reduction of blood loss and surgical time and, consequently, a decrease of the length of hospital stay (LOS), and an accelerated postoperative recovery [2,3]. The direct anterior approach (DAA) is considered a true minimally invasive technique for THA because it uses intermuscular planes without dissecting muscles [4].

In the Netherlands, the DAA is the most often used minimally invasive approach for THA and its numbers have increased from 4.7% in 2010 to almost 32% in 2018, whereas the posterolateral approach (PLA) remains the most performed approach [5]. Opponents of the DAA suggest that it is a technically more demanding approach, has a steep learning curve, and that there is a higher risk for revision because of femoral loosening [6–8]. However, this proposed femoral loosening might be affected by the stem design [9].

Several systematic reviews have been performed to assess differences between the DAA and the PLA in terms of perioperative and functional outcomes, with varying results [6,10–12]. The main limitation of these reviews is that they included only a few

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to https://doi.org/10.1016/j.arth.2021.05.009.

* Address correspondence to: Kyrill Rykov, MD, Department of Orthopaedic surgery, Martini Hospital Groningen, the Netherlands.

https://doi.org/10.1016/j.arth.2021.05.009
0883-5403/

randomized controlled trials that reported heterogeneous results and a short follow-up period. Furthermore, most of these reviews do not focus on the invasiveness of the procedure. Studies with biochemical serum markers have shown a beneficial tissue-sparing effect of the DAA [13,14]. However, this result was contradicted by other studies [15–17]. As serum markers may be influenced by patient characteristics and perioperative factors, we questioned their use for measuring invasiveness of approach in our previous study [17]. Moreover, a correlation between serum markers and functional outcomes has not been found [15,17,18].

Magnetic resonance imaging (MRI) is influenced less by patient characteristics and because the periarticular musculature can be visualized adequately, it could provide a more reliable assessment of the invasiveness of DAA. Furthermore, tendinopathies, fluid collections, and other adverse tissue reactions can be assessed with MRI [19]. In an MRI study, Bremer et al. found that the DAA resulted in a reduced tissue damage compared with the transgluteal approach [20]. Another study also found a beneficial effect of the DAA in preventing soft tissue damage compared with three other approaches [21]. However, these both are retrospective studies with several limitations. Because the gluteal musculature remains undisturbed with the DAA, the hypothesis is that these patients have less tissue damage postoperatively compared with approaches that damage the gluteal muscles. Pfirrmann et al. found that symptomatic patients had significant more fatty atrophy of the gluteus medius muscle compared with asymptomatic patients after THA [22]. This suggests that muscle damage is associated with muscle function and thus with functional outcome. However, few studies exist that investigate the association between functional outcomes and muscle damage. Müller et al. described less damage and better functional outcomes with the minimally invasive anterolateral approach than the lateral approach [23]. Another randomized controlled trial found that the DAA resulted in a decrease of muscle damage to the gluteal musculature compared with the lateral approach, however, they did not find any correlation with functional outcomes [14]. The authors suggested that the approach and the amount of muscle damage do not have any influence on clinical outcome. However, as the sample size of the study was based on serum markers and not on functional outcome, this study might have been underpowered to find an actual effect.

To the authors' best knowledge, no randomized controlled trials exist that measure muscle damage by means of MRI between the DAA and the PLA. Therefore, we performed a randomized controlled MRI study to measure the degree of muscle damage between the DAA and the PLA.

Methods

Patient Selection

We performed a longitudinal randomized controlled trial. Patients with symptomatic primary or secondary osteoarthritis between the ages 18 and 70 years were included in the study and were followed up to one year postoperatively. Patients with a history of previous surgery of the ipsilateral hip, peripheral neuropathy, (active) arthritis, history of cerebrovascular disease, or cognitive impairments were excluded. A cemented acetabular component (Stanmore, Biomet Corporation, the Netherlands) and an uncemented femoral component (Taperloc, Biomet Corporation, the Netherlands) were placed in all patients. Patients of 70 years and older were excluded for two reasons. First, muscle function and mass are known to decline and muscle atrophy to increase in elderly patients [24,25], and older patients are more sensitive to muscle damage [26]. Second, patients younger than 70 years have good bone stock, and an uncemented femoral component is placed

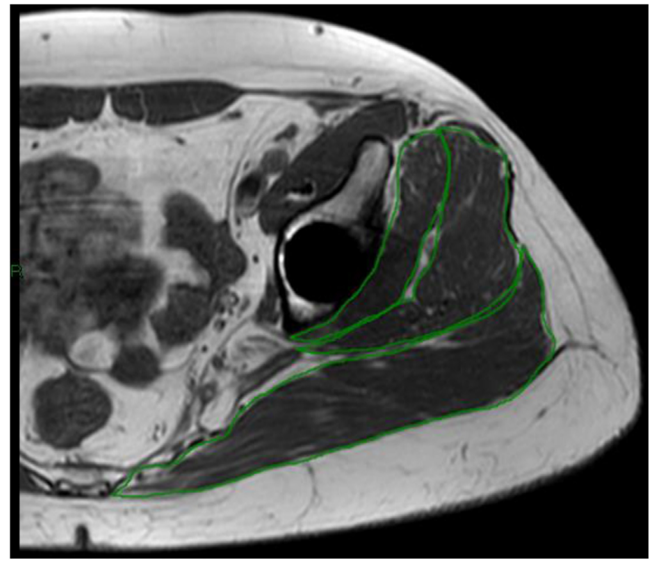

Fig. 1. MRI muscle surface measurement of the gluteal muscles.

in this group of patients in our hospital. The femoral component that is used in the study is made out of titanium alloy, which is nonferromagnetic and therefore produces less scattering on MRI for better assessment of the muscles. The surgical technique is described in the supplemental files.

The study has been approved by the medical ethics committee (RTPO nr.894, RTPO Leeuwarden, the Netherlands) and was registered in the Dutch Trial Register (NTR3926). An informed consent was obtained before randomization. A random allocation set of the type of THA approach was generated by means of a computer. These allocations were then sealed in consecutively numbered opaque envelopes. When the patient had given consent to be included in the trial, the THA approach was randomly assigned by opening the next sealed envelope by an independent investigator.

Sample Size Calculation

The aim of this study was to assess differences in muscle damage between the DAA and the PLA by means of MRI. De Anta-Diaz et al. compared the DAA with the direct lateral approach and found significant more muscle atrophy for gluteus medius and minimus [14]. Based on their results, a sample size was calculated with a power of 80% and an alpha of 5%, a sample size of 38 patients, 19 per group, was needed. Considering a potential lost to follow-up of 20%, 46 patients were included.

Data Collection

Demographic data, preoperative diagnosis, height, weight, body mass index, and American Society of Anaesthesiologists' grade were recorded preoperatively. Operative time and LOS were assessed. Any complication during surgery and during the follow-up period was noted. Functional outcome was assessed with the Harris hip score (HHS) and the Hip disability and Osteoarthritis and Outcome Score (HOOS) preoperatively and at the outpatient clinical visit one year postoperatively. The HHS was used to assess physician-reported functional status and range of motion [27]. The HOOS consists of five subscales: pain, other symptoms, function in daily living, function in sport and recreation, and hip-related quality of life. The Dutch version of the HOOS has been proven to be valid and reliable [28].

Table 1
Goutallier Grading System.

Goutallier Grade 0	No intramuscular fat is present
Goutallier grade 1	Some fatty streaks are present
Goutallier grade 2	Fat is evident, but less fat than muscle tissue
Goutallier grade 3	Equal amount of fat and muscle tissue
Goutallier grade 4	More fat than muscle tissue

Radiographic Measurements

All MRIs were performed on a Philips Achieva dStream 1.5T scanner, sw. version 5.4 (Philips MR Medical Systems International B.V., Best, Eindhoven, the Netherlands). Protocol consisted of metal artifact reduction sequences coronal STIR and T2W through the whole pelvis and axial T1W and STIR and sagittal T1W of the affected hip. The measurements were performed preoperatively and one year postoperatively on transversal plane using methods described in previous studies which showed good to excellent interobserver and intraobserver reliability (Intraclass correlation coefficient (ICC) values ranging from 0.72 to 0.99) [29,30].

Freehand region of interest muscle surface measurements and atrophy assessment of twelve ipsilateral hip muscles were applied on the axial T1W sequence (Fig. 1) [30,31]. MRIs of the flexor muscles (sartorius, iliacus, psoas, and rectus femoris), extensor muscle (gluteus maximus) abductor muscles (gluteus minimus, medius, and the tensor fascia latae), and the external rotators (piriformis, internal and external obturator, and the quadratus femoris) were assessed by one radiologist (TM), who was blinded for the THA approach.

Freehand region of interest muscle surface of the iliac and psoas muscle was measured at the anterior superior iliac spine level. External obturator, quadratus femoris, sartorius, rectus femoris, and tensor fascia latae muscles were measured at the level of the ischiadic tubercle. Piriformis muscle was measured at greater sciatic foramen level, and gluteus minimus, medius, and maximus at anterior inferior iliac spine level. Internal obturator muscle was measured at the level of the apparent greatest surface.

Fatty atrophy was assessed using the Goutallier grading system (Table 1) [32]. This grading system has been used in previous research for the grading of fatty atrophy of muscles after hip surgery [22,30].

Pelvic X-rays were obtained preoperatively and six weeks and one year postoperatively. Position of the femoral and acetabular components of the total hip prosthesis was measured on the anteroposterior pelvic X-ray that was taken six weeks postoperatively. TraumaCad software (Voyant Health, Petach-Tikva, Israel) was used for the measurements. Inclination of the acetabular component was measured by defining the angle between the interteardrop line and the cup. Version of the cup was measured by using the method described by Lewinnek et al. [33] Both the cup version and inclination have been proven to have a high interobserver and intraobserver reliability and have been proven to be a reliable and valid method when compared with the gold standard using 3D computed tomography scans [34–36]. Varus/valgus alignment of the stem was measured by taking the angle between the femoral shaft and the prosthetic component [37]. Acetabular, femoral, and global offset (sum of acetabular and femoral offset) measurements were obtained by measuring the differences between the preoperative and postoperative X-rays (Fig. 2). Offset ratio was measured by dividing the postoperative offset by the preoperative offset. A value < 1.0 meant an undercorrection of the offset, whereas a value ≥ 1.0 meant restoration or overcorrection of the offset. Preoperative and postoperative leg length discrepancies (LLD) were measured by drawing an interteardrop line and the most medial points of the lesser trochanter. Differences in LLD were calculated for the final analysis. Previous studies already showed good to excellent intraobserver and interobserver variation using the same measurements with this software [38]. However, we also assessed the interobserver variability for all outcomes. The X-rays of included patients were anonymized, randomized, and then independently assessed by two authors (KR and BH), who were thus blinded to the THA approach.

Statistical Analysis

To analyze the data SPSS (Statistical Package for the Social Sciences, Chicago, Illinois) was used. A *P*-value of <0.05 was considered to indicate statistical significance. Descriptive statistics (means, medians, standard deviations, and interquartile ranges) were used to describe the subject characteristics and the results of the groups. Student t-test was used for normally distributed continuous clinical parameters, otherwise the Mann-Whitney U-test was used.

For the analysis of muscle atrophy, the Goutallier classification was dichotomized into two grades of atrophy: a Goutallier grade of 0 or 1 was considered as no or mild atrophy and a grade ≥ 2 as moderate or severe atrophy. This dichotomization was based both on previous studies and the fact that a muscle atrophy grade of two and higher is more frequently found in symptomatic patients after THA [14,22]. The chi-square test was used to assess differences in the preoperative and postoperative muscle atrophy between the DAA and PLA.

To assess differences in muscle surface measurements between the preoperative and postoperative muscle surface within the same approach, the Wilcoxon signed rank test was used. Linear regression analysis was performed to assess postoperative differences in muscle surface between the DAA and PLA. In this analysis, the preoperative muscle surface values were added, to correct for differences at baseline between the approaches. Correlation analysis for muscle atrophy and muscle surface and the preoperative and postoperative differences in leg length and femoral and global offset was performed with the Spearman test.

Intraclass correlation coefficients were calculated to determine the interobserver variability of the measurements of the position of the total hip prosthesis. Values < 0 were considered as a poor agreement, 0.01-0.20 slight, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 substantial, and 0.81-0.99 as almost perfect agreement [39]. Differences in cup and stem position and offset measurements between the approaches were measured using the Mann-Whitney U-test. Repeated measures ANOVA were used to assess differences in leg length preoperatively and postoperatively.

Results

No significant differences were found in patients' characteristics between DAA and PLA groups (Table 2). For all 46 patients data regarding functional outcome and radiographic measurements were available, as there was no loss to follow-up at the final follow-up. For the MRI measurements, 45 patients were analyzed, as one patient in the DAA group was unwilling to undergo the one-year postoperative MRI measurement because of claustrophobia (Fig. 3). Furthermore, one female patient in the DAA group had an absent quadratus femoris muscle, an anatomic variety which only has been described in a few case reports. No differences in muscle surface were found for other muscles in this patient.

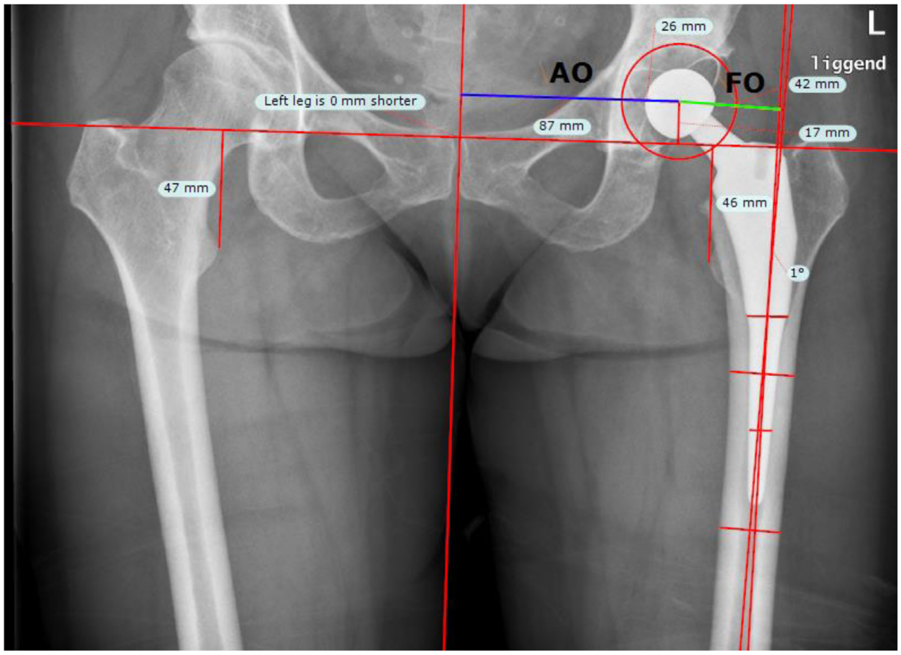

Fig. 2. Postoperative offset measurement.

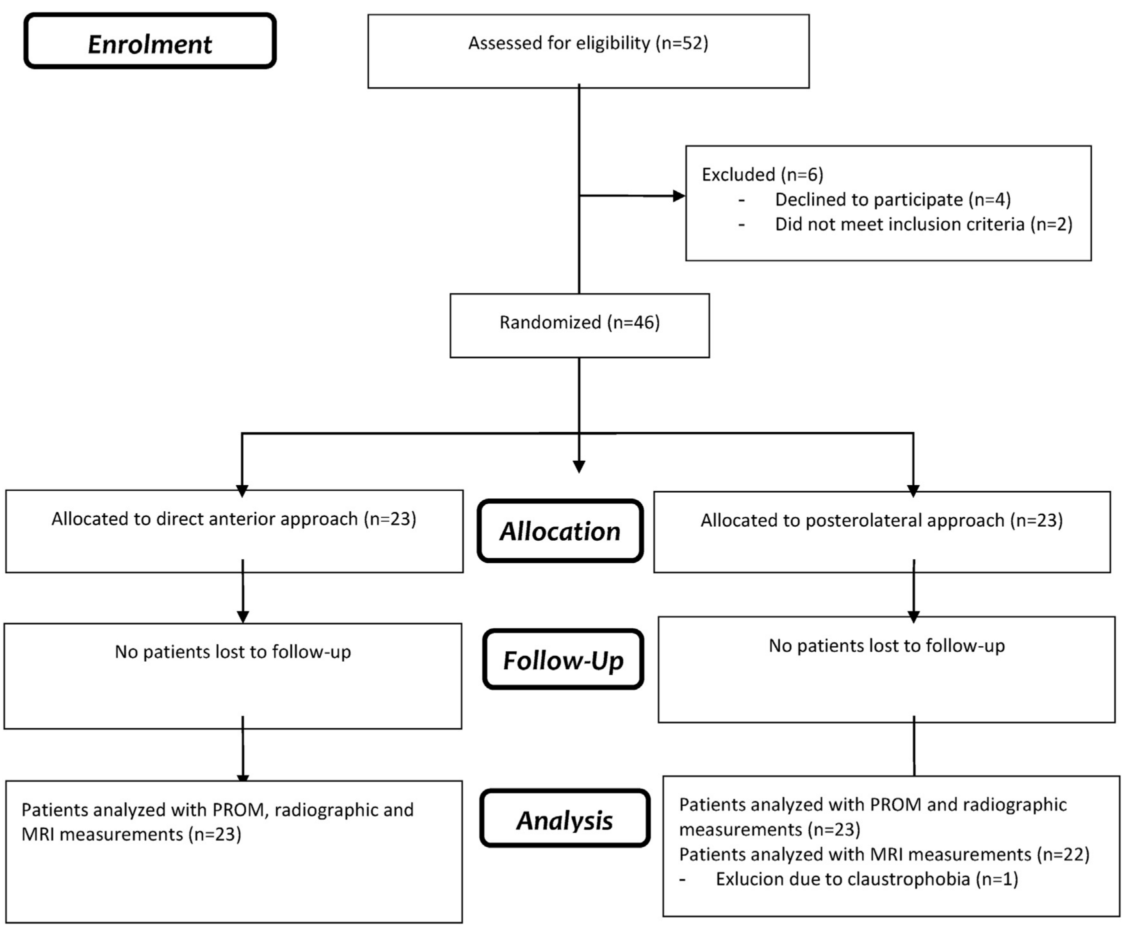

Fig. 3. CONSORT flow chart.

Table 2
Demographic and Perioperative Data.

Perioperative Data	DAA (N = 23)	PLA (N = 23)	*P*-Value
Gender (male/female)[a]	8/15	11/12	.37
Age[b]	62 [9]	63 [15]	.34
BMI[b]	27.8 [7.3]	28.6 [8.4]	.83
ASA grade[a]			.42
1	9	10	
2	14	13	
Operation side (left/right)[a]	13/10	9/14	.24
Anesthesia (spinal/general)[a]	19/4	20/3	.68
Preoperative Hb (mmol/L)[c]	9.3 [0.7]	9.1 [0.8]	.30
Postoperative Hb (mmol/L)[c]	7.8 [0.9]	7.8 [0.9]	.97
Surgical time (min) [c]	71 [7]	62 [7]	.001
Blood loss (mL)[b]	340.1 [135.3]	245.2 [259.9]	.21
LOS (d) [b]	1.0 [1]	1.0 [1]	.95

DAA, direct anterior approach; PLA, posterolateral approach; BMI, body mass index; ASA, American Society of Anaesthesiologists' grade; Hb, hemoglobin; LOS, length of hospital stay.
[a] Data are presented as N.
[b] Data presented as median [interquartile range].
[c] Data are presented as mean [SD].

Demographics and Perioperative Data

Surgical time was 9 minutes longer in the DAA group ($P = .001$). This had no effect on the amount of blood loss, postoperative Hb levels or LOS, and most patients could be discharged one day postoperatively (Table 2). There were no statistically significant differences regarding other perioperative variables.

Muscle Atrophy and Muscle Surface Measurements

Table 3 shows the differences in the incidence muscle atrophy in both groups. In the DAA group, a decrease in the number of patients with muscle atrophy was found between the preoperatively and postoperatively. An increase was seen for the TFL, the piriformis, and the obturator muscles. In the PLA group, an increase in the number of patients was seen for the piriformis and obturator muscles.

Between the approaches, the TFL showed a higher incidence of atrophy one year postoperatively compared in the DAA group. For the PLA group, the external obturator muscle showed a significant increase in the incidence of muscle atrophy and a trend for muscle atrophy was seen for the internal obturator.

Muscle surface measurements showed a significant increase of the rectus femoris, sartorius, and quadratus femoris postoperatively in both groups. In addition, an increase of the gluteus medius and iliacus was seen in the PLA group. However, this increase was nonsignificant between the groups. A significant difference between the groups was found one year postoperatively for the psoas muscle in favor of the PLA group. Furthermore, as for muscle atrophy, a significant decrease in muscle surface for the piriformis and the obturator muscles in both groups one year

Table 3
Postoperative Muscle Atrophy in Accordance With the Dichotomized Goutallier Score[a].

Muscles	DAA (N = 22)		PLA (N = 23)		*P*-Value
	No Atrophy	Atrophy	No Atrophy	Atrophy	
Gluteus minimus					
• Preoperative	9 [41%]	13 [59%]	13 [57%]	10 [43%]	
• Postoperative	8 [36%]	14 [64%]	14 [61%]	9 [39%]	.20
Gluteus medius					
• Preoperative	9 [41%]	13 [59%]	21 [91%]	2 [9%]	
• Postoperative	20 [91%]	2 [9%]	21 [91%]	2 [9%]	.96
Gluteus maximus					
• Preoperative	15 [68%]	7 [32%]	13 [57%]	10 [43%]	
• Postoperative	15 [68%]	7 [32%]	13 [57%]	10 [43%]	.42
Tensor facia latae					
• Preoperative	15 [68%]	7 [32%]	18 [78%]	5 [22%]	
• Postoperative	11 [50%]	11 [50%]	18 [78%]	5 [22%]	.048
Rectus femoris					
• Preoperative	22 [100%]	0 [0%]	23 [100%]	0 [0%]	
• Postoperative	22 [100%]	0 [0%]	23 [100%]	0 [0%]	1.00
Sartorius					
• Preoperative	21 [95%]	1 [5%]	22 [96%]	1 [4%]	
• Postoperative	21 [95%]	1 [5%]	23 [100%]	0 [0%]	.30
Iliacus					
• Preoperative	22 [100%]	0 [0%]	23 [100%]	0 [0%]	
• Postoperative	22 [100%]	0 [0%]	23 [100%]	0 [0%]	1.00
Psoas					
• Preoperative	22 [100%]	0 [0%]	23 [100%]	0 [0%]	
• Postoperative	21 [95%]	1 [5%]	23 [100%]	0 [0%]	.30
Quadratus femoris					
• Preoperative	20 [95%]	1 [5%]	22 [96%]	1 [4%]	
• Postoperative	21 [100%]	0 [0%]	20 [87%]	3 [13%]	.09
Piriformis					
• Preoperative	22 [100%]	0 [0%]	23 [100%]	0 [0%]	
• Postoperative	14 [64%]	8 [36%]	11 [48%]	12 [52%]	.29
Obturator externus					
• Preoperative	22 [100%]	0 [0%]	23 [100%]	0 [0%]	
• Postoperative	18 [82%]	4 [18%]	7 [30%]	16 [70%]	.001
Obturator internus					
• Preoperative	22 [100%]	0 [0%]	23 [100%]	0 [0%]	
• Postoperative	10 [45%]	12 [55%]	5 [22%]	17 [78%]	.11

Data are presented as N [%].
DAA, direct anterior approach; PLA, posterolateral approach; Gtl, Goutallier classification with values 0-1 as no or mild atrophy, and values 2-4 as moderate of severe atrophy.
[a] A Goutallier grade of 0 or 1 was considered as no or mild atrophy and a grade ≥2 as moderate or severe atrophy.

Table 4
Muscle Surface Measurements.

Muscles	DAA (N = 22)	PLA (N = 23)	Regr. Co Eff. (95% CI)	*P*-Value
Gluteus minimus				
Preoperative	12.54 (3.12)	14.30 (3.39)	0.9	
Postoperative	11.52 (2.61)	13.45 (3.05)	(−0.4 to 2.2)	
Postoperative difference				.19
P-value	.07	.07		
Gluteus medius				
Preoperative	26.97 (5.99)	23.70 (4.95)	2.0	
Postoperative	26.63 (5.13)	26.94 (5.36)	(−1.0 to 4.9)	
Postoperative difference				.19
P-value	.69	.02		
Gluteus maximus				
Preoperative	43.87 (9.02)	41.59 (9.97)	−0.01	
Postoperative	43.96 (8.24)	42.10 (9.92)	(−3.1 to 3.1)	
Postoperative difference				.99
P-value	.71	.52		
Tensor fascia latae				
Preoperative	7.51 (2.54)	7.37 (2.11)	−0.3	
Postoperative	7.50 (2.87)	7.11 (1.81)	(−1.0 to 0.5)	
Postoperative difference				.46
P-value	.69	.28		
Rectus femoris				
Preoperative	6.19 (1.71)	6.16 (1.94)	0.2	
Postoperative	6.50 (1.90)	6.70 (1.75)	(−0.4 to 0.8)	
Postoperative difference				.46
P-value	.10	.03		
Sartorius				
Preoperative	3.65 (0.90)	3.46 (0.92)	−0.02	
Postoperative	3.79 (0.98)	3.60 (0.86)	(−0.2 to 0.2)	
Postoperative difference				.84
P-value	.14	.02		
Iliacus				
Preoperative	11.76 (4.19)	11.23 (3.63)	0.9	
Postoperative	11.46 (3.94)	11.87 (3.46)	(−0.1 to 1.8)	
Postoperative difference				.08
P-value	.53	.03		
Psoas				
Preoperative	6.53 (2.68)	6.76 (2.99)	0.8	
Postoperative	6.21 (2.65)	7.04 (2.86)	(0.2 to 1.4)	
Postoperative difference				.02
P-value	.27	.16		
Quadratus femoris				
Preoperative	5.76 (2.31)	4.80 (2.29)	0.5	
Postoperative	6.26 (1.95)	5.92 (3.27)	(−0.6 to 1.6)	
Postoperative difference				.37
P-value	.07	.001		
Piriformis				
Preoperative	9.16 (3.67)	8.64 (2.60)	0.2	
Postoperative	5.93 (2.70)	5.91 (1.68)	(−0.8 to 1.3)	
Postoperative difference				.66
P-value	<.001	<.001		
Obturator internus				
Preoperative	10.30 (1.98)	10.49 (2.27)	−1.2	
Postoperative	7.31 (1.20)	6.13 (1.77)	(−1.9 to −0.6)	
Postoperative difference				<.001
P-value	<.001	<.001		
Obturator externus				
Preoperative	22.49 (4.68)	22.79 (5.06)	−3.6	
Postoperative	20.13 (5.11)	17.01 (4.12)	(−6.1 to −1.2)	
Postoperative difference				.005
P-value	.02	<.001		

Data are presented as mean [SD].
DAA, direct anterior approach; PLA, posterolateral approach; Regr. Co Eff., regression coefficient; 95% CI = 95% confidence interval.

postoperatively. The only significant difference between the groups was seen for both obturator muscles (Table 4).

For the DAA, a positive correlation was found for muscle surface of the gluteus medius and difference in preoperative and postoperative leg length (r = 0.46, *P* = .03). A negative correlation was found for the muscle surface of the TFL and increase in femoral offset (r = −0.57, *P* = .006). In the PLA group, a negative correlation between the muscle surface of the piriformis and increase in femoral offset (r = −0.43, *P* = .04) was seen and a positive correlation between the increase of muscle atrophy of the internal obturator and increase in femoral offset (r = 0.43, *P* = .047). No significant correlations were found for other muscles.

Radiographic Measurements

Interobserver variation showed excellent reliability for both cup inclination (ICC 0.99, 95% CI: 0.97-0.99) and version (ICC 0.97, 95% CI: 0.94-0.98) and good reliability for stem alignment (ICC 0.65, 95%

Table 5
Radiographic Measurements 6 wk Postoperatively.

Radiographic Measurements	DAA (N = 23)	PLA (N = 23)	*P*-Value
Cup inclination[a]	47.0 [6.0]	52.0 [6.0]	<.001
Cup version[a]	18.0 [5.0]	17.0 [6.0]	.48
Stem alignment[a]	2.0 [2.0]	1.0 [1.0]	.28
Preoperative LLD[b]	−1.0 [4.0]	−1.0 [6.0]	.60
Postoperative LLD[b]	1.0 [6.0]	0.0 [6.0]	.84
Difference preoperative and postoperative LLD[b]	1.0 [6.0]	3.0 [5.0]	.33
Acetabular offset[b]	23.0 [8.0]	30.0 [7.0]	.43
Femoral offset[b]	46.0 [7.0]	47.0 [11.0]	.73
Global offset[b]	76.0 [10.0]	74.0 [16.0]	.90
Difference in acetabular offset[b]	−4.0 [3.0]	−7.0 [7.0]	.03
Difference in femoral offset[b]	7.0 [9.0]	10.0 [11.0]	.18
Difference in global offset[b]	4.0 [5.0]	5.0 [7.0]	.60
Acetabular offset ratio postop:preop[b]	0.5 [0.2]	0.8 [0.2]	.04
Femoral offset ratio postop:preop[b]	1.2 [0.3]	1.2 [0.3]	.17
Global offset ratio postop:preop[b]	1.1 [0.1]	1.1 [0.1]	.56

DAA, direct anterior approach; PLA, posterolateral approach; LLD, leg length discrepancy.
[a] Data presented as median [interquartile range] degrees.
[b] Data presented as median [interquartile range] in mm.

CI 0.14-0.85). Preoperative and postoperative LLD had an excellent reliability (ICC 0.83, 95% CI 0.71-0.91 and 0.85, 95% CI 0.74-0.92, respectively).

Interobserver measurements of preoperative offset also showed excellent reliability for femoral offset (ICC 0.87, 95% CI 0.54-0.95) and good reliability for acetabular offset (ICC 0.66, 95% CI 0.124-0.857). Good interobserver reliability was found for postoperative femoral offset (ICC 0.79, 95% CI: 0.28-0.92) and acetabular offset (ICC 0.71, 95% CI 0.39-0.86).

A significant higher cup inclination was found for the PLA, and the number of outliers outside the “Lewinnek safe zones” was also greater following (Table 5 and Fig. 4). Furthermore, difference between the preoperative and postoperative acetabular offset and offset ratio was higher for the PLA.

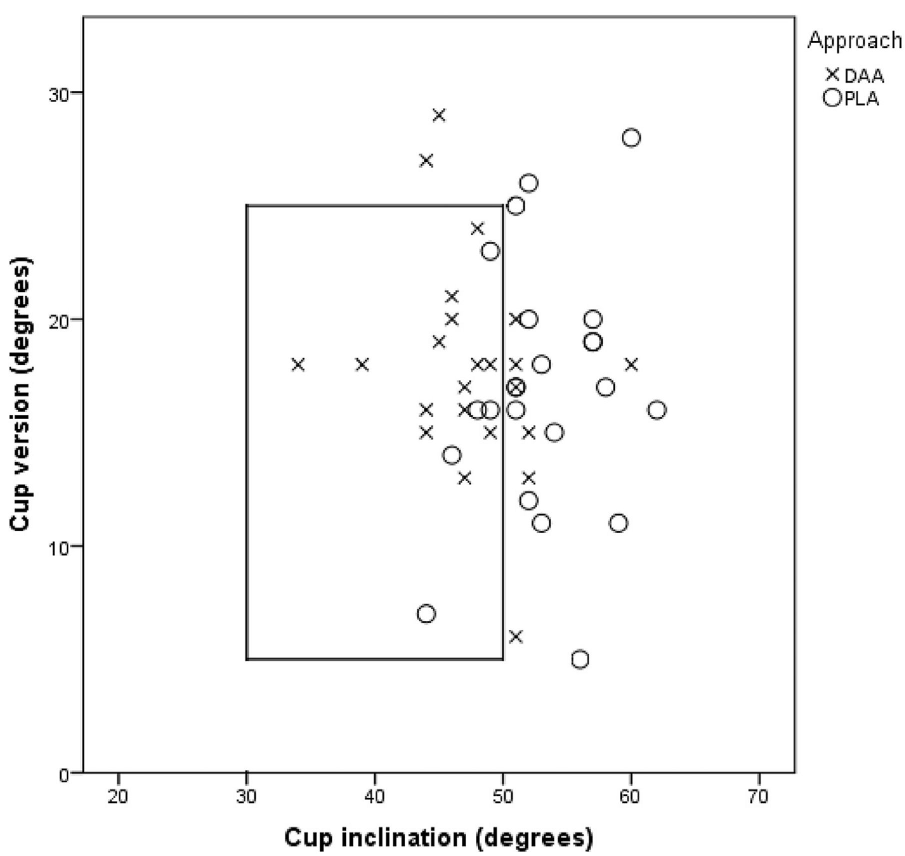

Fig. 4. Cup version and inclination.

Table 6
Functional Outcomes One Year Postoperatively.

Functional Scores	DAA (N = 23)	PLA (N = 23)	*P*-Value
HHS preoperative[a]	51.7 [6.7]	51.2 [8.9]	.85
HHS 1y postoperative[a]	98.1 [2.8]	97.4 [4.5]	.58
HOOS preoperative[a]	33.4 [16.0]	32.5 [13.5]	.87
HOOS 1y postoperative[a]	85.2 [20.3]	85.1 [15.7]	.99

Data are presented as N.
DAA, direct anterior approach; PLA, posterolateral approach; HHS, Harris hip score; HOOS, Hip disability and Osteoarthritis Outcome Score.
[a] Data are presented as mean [SD].

Table 7
Complications.

Complications	DAA (N = 23)	PLA (N = 23)
Type of complication		
Deep infection with reoperation	2	1
Dislocation with reoperation	10	11
NFCL lesion reported	1	0
Seroma formation	1	0
Myocardial infarction	0	1
Other (not surgery related)	0	1
Total	5	4

DAA, direct anterior approach; PLA, posterolateral approach; NFCL, nervus femoris cutaneous lateralis.

Functional Outcomes and Complications

No statistically significant differences in functional outcomes were found between the two groups (Table 6). A total of nine complications were registered, five in the DAA group and four in the PLA group (Table 7). All patients with an infection were successfully treated with a debridement only. One patient who was treated for an infection had a dislocation shortly after the second operation which was treated with a closed reduction. In the PLA group, one patient with secondary osteoarthritis due to a previous post-Perthes disease and a preoperative large LLD had a dislocation, which was treated with a revision of the prosthesis.

Discussion

In the last decades, an increase is seen in minimally invasive techniques for THA because of their proposed benefits. The DAA is proposed to be a true minimally invasive approach because it uses intermuscular planes without dissecting any muscles. Previous comparative studies between the DAA and the PLA on muscle damage have shown contradictive results. Therefore we performed a randomized controlled trial in which muscle damage was compared using MRI. To date, no studies exist that have evaluated the muscle damage between these two approaches in a randomized trial.

We found increased fatty atrophy of the TFL for the DAA, although no decrease was seen in muscle surface. An increase in femoral offset also had a negative influence on the muscle surface of the TFL in the DAA group, although the mean muscle surface did not show a significant difference. Fatty atrophy can be explained by traction on the TFL during the exposure of the hip in the DAA and the fact that the circumflex artery is cauterized during the approach. When the insertion of the muscle on the iliac crest is not damaged, regeneration and restoration of the muscle can be expected after three to six months, which may explain why the muscle surface remains the same. In the DAA group, the number of patients with muscle atrophy of the gluteus medius was lower than the PLA group. This might be because it has been shown that patients with osteoarthritis show a greater muscle atrophy of the gluteal muscles [40]. Because the gluteal musculature is spared in the DAA and the patient can ambulate without pain and with a normal gait postoperatively, the atrophied muscles can be restored to normal. This effect might contribute to a faster functional recovery after the DAA. Furthermore, for both approaches, an increase in fatty atrophy and a decrease in muscle surface for the piriformis and internal and external obturator were found. For the PLA, the external obturator showed a significant increase in muscle atrophy and the same trend was also seen for the internal obturator compared with the DAA. Both obturator muscles also had a significant decrease in muscle surface when compared with the DAA. In contrast to several other studies, in which the Goutallier grade was assessed as continuous parameters, we chose to dichotomize the Goutallier grade because it is a nominal scale. Previous studies in shoulder surgery have shown that a grade of two and higher has a negative influence on functional outcome compared with a grade of 0 or 1 [41]. We also used this dichotomization based on a previous studies [14,22]. This difference in analysis can have an influence when comparing our data with that of other studies. Therefore, we also analyzed the Goutallier classification as a continuous parameter. There we found comparable results, with the addition that the internal obturator was significantly more affected after PLA (Supplemental Table 1).

For the femoral exposure in the DAA, the superior capsule is released as well as the conjoined tendon of the gemelli and internal obturator muscles in most cases. Dissection of the piriformis and the external rotators is less frequently needed for adequate exposure [42]. However, traction on the femur during the exposure could potentially damage the posterior muscles. In our study, the release of the capsule, and conjoined tendon in some cases, resulted in adequate exposure, and no additional releases were necessary. Other intraoperative muscle damage that could have influenced the results was not observed. Cadaveric studies comparing the anterior and posterior approach showed that the posterior structures are equally damaged with both approaches [43,44]. These studies are limited because of the regeneration in time cannot be objectified and the lack of clinical correlation. More important, cadaveric muscles are less strong, and the failure to stress is lower than in living muscle tissue [45].

Previous studies showed that there is a high failure rate of posterior tissue repair after the PLA [46,47]. In a retrospective MRI study by Agten et al. also found that the external rotators are damaged more often in the posterior approaches when compared with the anterior or anterolateral approach [21].

One study comparing the anterior and posterior approach found a decreased external and internal range of motion in the posterior group [48]. Although there is conflicting evidence on the clinical importance of the posterior soft tissue repair, studies suggest that this has a negative influence on dislocation rate and functional outcome [49–51]. In shoulder surgery, it has been shown that a successful tendon repair can stop fatty infiltration and muscle atrophy can be restored. However, in case of failed tendon repair, the fatty infiltration and muscle atrophy proceeds for three months before it stabilizes [52]. Although there are no studies that have described this in hip surgery, it can be hypothesized that similar muscle changes take place after THA. With the DAA, the external rotators are not dissected, and therefore, one can expect some recovery of muscles. Moreover, Uemura et al. showed that muscle recovery can be seen even after two years after THA [53].

The most interesting finding in our study was an actual increase in postoperative muscle surface for the rectus femoris, sartorius, and quadratus femoris for both approaches compared with the preoperative measurement. A significant increase was also found for the gluteus medius and iliacus muscles in the PLA. No significant differences were found between the approaches for these muscles. A significant difference in muscle surface was found for the psoas in favor of the PLA. Several reasons can be given for these findings. First, we found an increase in femoral offset in the PLA, although this was not significantly different from the DAA. Increase in femoral offset could result in an increased abductor strength and better functional outcomes [54,55]. This might be a reason for hypertrophy of the gluteus medius muscle. However, no correlation was found between the offset and hypertrophy and an additional subgroup analysis for the increase in femoral offset and increase in muscle surface of the gluteus medius, also found no correlation, probably due to the small numbers. Rasch et al. also described similar findings with increase in muscle surface of the adductors, iliopsoas, vastus muscles, and hamstrings six months and two years after THA. However, muscle surface of the gluteus medius remained unchanged. Interestingly, despite the increase in muscle surface in their study, most muscles showed increase in muscle atrophy at two years postoperatively [56]. The difference with our study is that their study used CT scans for the measurements and the landmarks were potentially different.

No differences were found in functional outcomes measured by the HHS and HOOS one year postoperatively. To date, no randomized controlled trials exist that correlated MRI findings with clinical outcomes between the DAA and PLA. One study that compared the anterior approach with the lateral approach showed comparable results in functional outcomes, despite less muscle damage in the anterior approach group [14]. In a prospective cohort study, Winther et al. compared the posterior, anterior, and lateral approaches and also compared the operated and the nonoperated legs. They found no differences in functional outcomes between the anterior and posterior group one year postoperatively. However, when compared with the nonoperated leg, leg symmetry for leg press and abduction strength was reached only in the posterior approach group one year postoperatively. They argued that the posterior approach had the fastest muscular improvement [57]. Several other studies analyzing differences between the DAA and the PLA in regard to functional outcome and gait analysis showed beneficial functional outcomes for the DAA on the short term [10−12,58−60]. Furthermore, no differences between the approaches were found after a follow-up of five years in one study [61]. The reason for the faster short-term recovery in DAA is probably the muscle sparing character of the approach and that the gluteal musculature is spared. During leg stance, the gluteus minimus and medius play an important role in pelvic stability. It has been shown that patients with osteoarthritis who have strong hip abductor and flexor muscles have the best gait quality [62]. Moreover, Pfirmann et al. found that symptomatic patients after THA had significant more fatty atrophy of the gluteus medius muscle compared with asymptomatic patients [22]. In our study, the femoral offset was slightly more increased in the PLA group in comparison with the DAA. Because muscles need time to adapt to their new position and regain strength, functional parameters may be diminished in the PLA. This could explain why there is a slower recovery in patients operated via the PLA during the first three months. Therefore, the DAA can result in a faster recovery, faster return to daily activities, and it also has potential financial benefits [63].

Looking at the position of the cup and stem, we found that the inclination for the DAA was within the “Lewinnek safe zones,” whereas the inclination of the PLA was found more often outside the safe zone. The cup version was within the “safe zones,” and no significant differences were found between the approaches. Stem alignment and differences in leg length also showed no significant differences. Although the confidence interval of our interobserver variation for stem alignment was large, the difference in degrees was low and not clinically relevant. Comparable results were seen in the study by Lin et al. [64] However, no differences were seen in another randomized trial and two recent meta-analyses and desired angles can be achieved in both approaches [11,12,65]. We observed two patients with a dislocation, one in each group. The patient in the PLA group also needed a revision because of the dislocation.

Our study does have some limitations. First, this is the first study in which twelve muscles in these two approaches are compared. Therefore, the power to find differences for some muscles might be low. However, we did find differences that are both statistically significant as well as clinically relevant. In addition, we only included patients who were below the age of 70 years. These patients have more muscle mass compared with older patients. In the DAA, traction on stiff muscles does have some influence on muscle damage. It would be interesting to evaluate muscle damage in the older population. Furthermore, we only have one postoperative MRI measurement. Although our study is the only one that measured the amount of muscle damage both preoperatively and postoperatively, it would be interesting to assess the amount of muscle damage after three to six months and after two years postoperatively to gain insight into the level of muscle damage at the more long-term. Fourth, although all MRIs were performed with the same protocol, the rotation of the leg and pelvic tilt during the scan might have been different between patients, which may have influenced the measurements. However, because this is a randomized controlled trial, the same issues would occur in both groups, thereby reducing chance of bias. Moreover, in the study by Uemura et al. the difference in pelvic tilt between the first and second scans was only 0.2° [53]. Finally, although we did not find differences in our study groups in the HHS and HOOS scores, we did not assess postoperative gait or muscle strength that could have been associated with the MRI outcomes. To address this issue, we are now performing a larger randomized trial to compare functional outcomes, as well as PROMs both on the short-term and longer term follow-up for these approaches [66].

In conclusion, we found that muscle damage is present in both approaches. An increased muscle atrophy was found for the external obturator, and a decreased muscle surface was seen for both obturator muscles after the PLA compared with the DAA one year postoperatively. Compared with the PLA, the DAA showed an increased muscle atrophy for the tensor fascia latae muscle and a decreased muscle surface area for the psoas muscle at the final follow-up. In both approaches, a postoperative increase in muscle surface was seen for the rectus femoris, sartorius, and quadratus femoris. In addition, the muscle surfaces of the gluteus medius and iliacus showed an increase in the PLA group. No postoperative difference was found between the approaches for these muscles.

Furthermore, future studies should focus on differences in muscle damage in older patients, as well as on gait parameters, leg strength, and patient-related outcome measurements between the two approaches and correlate these results with objective muscle damage measurements both on short term and long term. Until results from well-designed, large randomized controlled trials are available, the choice for approach should be surgeon dependent because both approaches provide excellent outcomes.

References

[1] Husted H, Jensen CM, Solgaard S, Kehlet H. Reduced length of stay following hip and knee arthroplasty in Denmark 2000â€"2009: from research to implementation. Arch Orthop Trauma Surg 2012;132:1.

[2] Xu CP, Li X, Song JQ, Cui Z, Yu B. Mini-incision versus standard incision total hip arthroplasty regarding surgical outcomes: a systematic review and meta-analysis of randomized controlled trials. PLoS One 2013;8:11.

[3] Smith TO, Blake V, Hing CB. Minimally invasive versus conventional exposure for total hip arthroplasty: a systematic review and meta-analysis of clinical and radiological outcomes. Int Orthop 2011;35:2.
[4] Rachbauer F, Krismer M. Minimally invasive total hip arthroplasty via direct anterior approach. Oper Orthop Traumatol 2008;20:3.
[5] Dutch Arthroplasty Register (LROI). Annual Report 2019; 2019. https://www.lroi-report.nl/app/uploads/2020/10/PDF-Online-LROI-annual-report-2019-min.pdf [accessed 28.05.21].
[6] Meermans G, Konan S, Das R, Volpin A, Haddad FS. The direct anterior approach in total hip arthroplasty: a systematic review of the literature. Bone Joint J 2017;99-B:6.
[7] Zijlstra WP, De Hartog B, Van Steenbergen LN, Scheurs BW, Nelissen RGHH. Effect of femoral head size and surgical approach on risk of revision for dislocation after total hip arthroplasty. Acta Orthop 2017.
[8] Meneghini RM, Elston AS, Chen AF, Kheir MM, Fehring TK, Springer BD. Direct anterior approach: risk factor for early femoral failure of cementless total hip arthroplasty: a multicenter study. J Bone Joint Surg Am 2017;99:2.
[9] Janssen L, Wijnands KAP, Janssen D, Janssen MWHE, Morrenhof JW. Do stem design and surgical approach influence early aseptic loosening in cementless THA? Clin Orthop Relat Res 2018;476:6.
[10] Wang Z, Hou JZ, Wu CH, Zhou YJ, Gu XM, Wang HH, et al. A systematic review and meta-analysis of direct anterior approach versus posterior approach in total hip arthroplasty. J Orthop Surg Res 2018;13:1.
[11] Peng L, Zeng Y, Wu Y, Zeng J, Liu Y, Shen B, et al. Functional and radiographic outcomes of primary total hip arthroplasty between direct anterior approach and posterior approach: a systematic review and meta-analysis. BMC Musculoskelet Disord 2020;21:1.
[12] Chen W, Sun JN, Zhang Y, Zhang Y, Chen XY, Feng S. Direct anterior versus posterolateral approaches for clinical outcomes after total hip arthroplasty: a systematic review and meta-analysis. J Orthop Surg Res 2020;15:1.
[13] Bergin PF, Doppelt JD, Kephart CJ, Benke MT, Graeter JH, Holmes AS, et al. Comparison of minimally invasive direct anterior versus posterior total hip arthroplasty based on inflammation and muscle damage markers. J Bone Joint Surg Am 2011;93:15.
[14] De Anta-Diaz B, Serralta-Gomis J, Lizaur-Utrilla A, Benavidez E, Lopez-Prats FA. No differences between direct anterior and lateral approach for primary total hip arthroplasty related to muscle damage or functional outcome. Int Orthop 2016.
[15] Mjaaland KE, Kivle K, Svenningsen S, Pripp AH, Nordsletten L. Comparison of markers for muscle damage, inflammation, and pain using minimally invasive direct anterior versus direct lateral approach in total hip arthroplasty: a prospective, randomized, controlled trial. J Orthop Res 2015.
[16] Pilot P, Kerens B, Draijer WF, Kort NP, ten Kate J, Buurman WA, et al. Is minimally invasive surgery less invasive in total hip replacement? A pilot study. Injury 2006;37(Suppl 5).
[17] Rykov K, Reininga IHF, Sietsma MS, Knobben BAS, Ten Have BLEF. Posterolateral vs direct anterior approach in total hip arthroplasty (polada trial): a randomized controlled trial to assess differences in serum markers. J Arthroplasty 2017;32:12.
[18] Poehling-Monaghan KL, Taunton MJ, Kamath AF, Trousdale RT, Sierra RJ, Pagnano MW. No correlation between serum markers and early functional outcome after contemporary THA. Clin Orthop Relat Res 2016.
[19] Fritz J, Lurie B, Miller TT, Potter HG. MR imaging of hip arthroplasty implants. Radiographics 2014;34:4.
[20] Bremer AK, Kalberer F, Pfirrmann CW, Dora C. Soft-tissue changes in hip abductor muscles and tendons after total hip replacement: comparison between the direct anterior and the transgluteal approaches. J Bone Joint Surg Br 2011;93:7.
[21] Agten CA, Sutter R, Dora C, Pfirrmann CW. MR imaging of soft tissue alterations after total hip arthroplasty: comparison of classic surgical approaches. Eur Radiol 2016.
[22] Pfirrmann CW, Notzli HP, Dora C, Hodler J, Zanetti M. Abductor tendons and muscles assessed at MR imaging after total hip arthroplasty in asymptomatic and symptomatic patients. Radiology 2005;235:3.
[23] Muller M, Tohtz S, Springer I, Dewey M, Perka C. Randomized controlled trial of abductor muscle damage in relation to the surgical approach for primary total hip replacement: minimally invasive anterolateral versus modified direct lateral approach. Arch Orthop Trauma Surg 2011;131:2.
[24] Suetta C, Aagaard P, Magnusson SP, Andersen LL, Sipila S, Rosted A, et al. Muscle size, neuromuscular activation, and rapid force characteristics in elderly men and women: effects of unilateral long-term disuse due to hip-osteoarthritis. J Appl Physiol (1985) 2007;102:3.
[25] Chi AS, Long SS, Zoga AC, Read PJ, Deely DM, Parker L, et al. Prevalence and pattern of gluteus medius and minimus tendon pathology and muscle atrophy in older individuals using MRI. Skeletal Radiol 2015;44:12.
[26] Merritt EK, Stec MJ, Thalacker-Mercer A, Windham ST, Cross JM, Shelley DP, et al. Heightened muscle inflammation susceptibility may impair regenerative capacity in aging humans. J Appl Physiol (1985) 2013;115:6.
[27] Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg Am 1969;51:4.
[28] de Groot IB, Reijman M, Terwee CB, Bierma-Zeinstra SM, Favejee M, Roos EM, et al. Validation of the Dutch version of the hip disability and osteoarthritis outcome score. Osteoarthritis Cartilage 2007;15:1.
[29] Lüdemann M, Kreutner J, Haddad D, Kenn W, Rudert M, Nöth U. MRI-based measurement of muscle damage after minimally invasive hip arthroplasty. Orthopade 2012;41:5.
[30] Kawasaki M, Hasegawa Y, Okura T, Ochiai S, Fujibayashi T. Muscle damage after total hip arthroplasty through the direct anterior approach for developmental dysplasia of the hip. J Arthroplasty 2017;32:8.
[31] Ludemann M, Kreutner J, Haddad D, Kenn W, Rudert M, Noth U. MRI-based measurement of muscle damage after minimally invasive hip arthroplasty. Orthopade 2012;41:5.
[32] Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. Clin Orthop Relat Res 1994;304:304.
[33] Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60:2.
[34] Nho JH, Lee YK, Kim HJ, Ha YC, Suh YS, Koo KH. Reliability and validity of measuring version of the acetabular component. J Bone Joint Surg Br 2012;94:1.
[35] Lu M, Zhou YX, Du H, Zhang J, Liu J. Reliability and validity of measuring acetabular component orientation by plain anteroposterior radiographs. Clin Orthop Relat Res 2013;471:9.
[36] Manjunath KS, Soruban V, Gopalakrishna KG. Evaluation of radiological methods of assessing cup anteversion in total hip replacement. Eur J Orthop Surg Traumatol 2015;25:8.
[37] Manaster BJ. From the RSNA refresher courses. Total hip arthroplasty: radiographic evaluation. Radiographics 1996;16:3.
[38] Kruse C, Rosenlund S, Broeng L, Overgaard S. Radiographic cup position following posterior and lateral approach to total hip arthroplasty. An explorative randomized controlled trial. PLoS One 2018;13:1.
[39] Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:1.
[40] Zacharias A, Pizzari T, English DJ, Kapakoulakis T, Green RA. Hip abductor muscle volume in hip osteoarthritis and matched controls. Osteoarthritis Cartilage 2016;24:10.
[41] Gladstone JN, Bishop JY, Lo IK, Flatow EL. Fatty infiltration and atrophy of the rotator cuff do not improve after rotator cuff repair and correlate with poor functional outcome. Am J Sports Med 2007;35:5.
[42] Zhao G, Zhu R, Jiang S, Xu C, Xu N, Wang Y. Soft tissue restrictors of femoral elevation in direct anterior approach-an anatomic study. J Orthop Surg Res 2018;13:1.
[43] Meneghini RM, Pagnano MW, Trousdale RT, Hozack WJ. Muscle damage during MIS total hip arthroplasty: Smith-Petersen versus posterior approach. Clin Orthop Relat Res 2006;453.
[44] Amanatullah DF, Masini MA, Roger DJ, Pagnano MW. Greater inadvertent muscle damage in direct anterior approach when compared with the direct superior approach for total hip arthroplasty. Bone Joint J 2016;98-B:8.
[45] Van Ee CA, Chasse AL, Myers BS. Quantifying skeletal muscle properties in cadaveric test specimens: effects of mechanical loading, postmortem time, and freezer storage. J Biomech Eng 2000;122:1.
[46] Stähelin T, Drittenbass L, Hersche O, Miehlke W, Munzinger U. Failure of capsular enhanced short external rotator repair after total hip replacement. Clin Orthop Relat Res 2004;420:199–204. https://doi.org/10.1097/00003086-200403000-00028.
[47] Loiba V, Stucinskas J, Robertsson O, Wingstrand H, Tarasevicius S. The analysis of posterior soft tissue repair durability after total hip arthroplasty in primary osteoarthritis patients. Hip Int 2015;25:5.
[48] Rathod PA, Orishimo KF, Kremenic IJ, Deshmukh AJ, Rodriguez JA. Similar improvement in gait parameters following direct anterior & posterior approach total hip arthroplasty. J Arthroplasty 2014;29:6.
[49] Rowan FE, Benjamin B, Pietrak JR, Haddad FS. Prevention of dislocation after total hip arthroplasty. J Arthroplasty 2018;33:1316–24. https://doi.org/10.1016/j.arth.2018.01.047.
[50] Yamaguchi T, Naito M, Asayama I, Kambe T, Fujisawa M, Ishiko T. The effect of posterolateral reconstruction on range of motion and muscle strength in total hip arthroplasty. J Arthroplasty 2003;18:347–51. https://doi.org/10.1054/arth.2003.50060.
[51] Wang ,T, Shao ,L, Xu ,W, Li ,F, Huang ,W, Surgical injury and repair of hip external rotators in THA via posterior approach: a three-dimensional MRI-evident quantitative prospective study.
[52] Wieser K, Joshy J, Filli L, Kriechling P, Sutter R, Fürnstahl P, et al. Changes of supraspinatus muscle volume and fat fraction after successful or failed arthroscopic rotator cuff repair. Am J Sports Med 2019;47:13.
[53] Uemura K, Takao M, Sakai T, Nishii T, Sugano N. Volume increases of the gluteus maximus, gluteus medius, and thigh muscles after hip arthroplasty. J Arthroplasty 2016;31:4.
[54] Asayama I, Chamnongkich S, Simpson KJ, Kinsey TL, Mahoney OM. Reconstructed hip joint position and abductor muscle strength after total hip arthroplasty. J Arthroplasty 2005;20:4.
[55] Clement ND, S Patrick-Patel R, MacDonald D, Breusch SJ. Total hip replacement: increasing femoral offset improves functional outcome. Arch Orthop Trauma Surg 2016;136:9.
[56] Rasch A, Byström AH, Dalén N, Martinez-Carranza N, Berg HE. Persisting muscle atrophy two years after replacement of the hip. J Bone Joint Surg Br 2009;91:5.

[57] Winther SB, Foss OA, Husby OS, Wik TS, Klaksvik J, Husby VS. Muscular strength and function after total hip arthroplasty performed with three different surgical approaches: one-year follow-up study. Hip Int 2019;29:4.

[58] Barrett WP, Turner SE, Leopold JP. Prospective randomized study of direct anterior vs postero-lateral approach for total hip arthroplasty. J Arthroplasty 2013;28:9.

[59] Taunton MJ, Trousdale RT, Sierra RJ, Kaufman K, Pagnano MW, John Charnley Award. Randomized clinical trial of direct anterior and miniposterior approach THA: which provides better functional recovery? Clin Orthop Relat Res 2018;476:2.

[60] Moyer R, Lanting B, Marsh J, Al-Jurayyan A, Churchill L, Howard J, et al. Postoperative gait mechanics after total hip arthroplasty: a systematic review and meta-analysis. JBJS Rev 2018;6:11.

[61] Barrett WP, Turner SE, Murphy JA, Flener JL, Alton TB. Prospective, randomized study of direct anterior approach vs posterolateral approach total hip arthroplasty: a concise 5-year follow-up evaluation. J Arthroplasty 2019;34:6.

[62] Rosenlund S, Holsgaard-Larsen A, Overgaard S, Jensen C. The gait deviation Index is associated with hip muscle strength and patient-reported outcome in patients with severe hip osteoarthritis-A cross-sectional study. PLoS One 2016;11:4.

[63] Miller LE, Martinson MS, Gondusky JS, Kamath AF, Boettner F, Bhattacharyya SK. Ninety-day postoperative cost in primary total hip arthroplasty: an economic model comparing surgical approaches. Clinicoecon Outcomes Res 2019;11.

[64] Lin TJ, Bendich I, Ha AS, Keeney BJ, Moschetti WE, Tomek IM. A comparison of radiographic outcomes after total hip arthroplasty between the posterior approach and direct anterior approach with intraoperative fluoroscopy. J Arthroplasty 2017;32:2.

[65] Zhao HY, Kang PD, Xia YY, Shi XJ, Nie Y, Pei FX. Comparison of early functional recovery after total hip arthroplasty using a direct anterior or posterolateral approach: a randomized controlled trial. J Arthroplasty 2017;32:11.

[66] Rykov K, Reininga IH, Knobben BA, Sietsma MS, Ten Have BL. The design of a randomised controlled trial to evaluate the (cost-) effectiveness of the posterolateral versus the direct anterior approach for THA (polada - trial). BMC Musculoskelet Disord 2016;17:1.

[67] den Hartog YM, Mathijssen NM, Vehmeijer SB. The less invasive anterior approach for total hip arthroplasty: a comparison to other approaches and an evaluation of the learning curve - a systematic review. Hip Int 2016;26:2.

Appendix

Surgical Technique

All surgical interventions were performed in a large teaching hospital. The patients were operated in a high-volume hospital by three orthopedic surgeons (BH, BK, and MS) who all have extensive experience with both approaches and are far beyond the proposed learning curve of 100 patients for the DAA [67]. For the DAA, the patient is placed in a supine decubitus position. The skin incision is made over and in the direction of the lateral part of the femoral head and neck. After division of skin and subcutis, the interval between the tensor fasciae latae muscle and the sartorius muscle is identified and the overlying fascia is opened. In this part of the operation, care was taken to avoid damaging the lateral femoral cutaneous nerve. The intermuscular plane between the tensor fasciae latae and sartorius muscles is developed further down to the hip capsule. Subsequently, the hip capsule is opened, allowing access to the hip joint. Next, osteotomy of the femoral neck, removal of the femoral head, and reaming of the acetabulum is performed. Subsequently, bone cement (Palacos, Heraeus Medical, the Netherlands) is pressurized into the acetabular cavity, followed by insertion of the acetabular cup. After reaming of the femur, the femoral component is placed without bone cement, followed by placement of a 28mm diameter head on the femoral component, repositioning of the joint and closure in layers.

For the PLA, the patient is placed in a lateral decubitus position. The skin incision is made over the greater trochanter to cranial, with a slight curve to posterior. After transection of the subcutis, the fascia latae and the gluteus maximus muscles are split. Next, the short external rotators, namely the piriformis, the inferior and superior gemellus, and the internal obturator muscles, are cut at the level of their insertion at the greater trochanter, so this approach is not muscle-sparing. After retraction of the short external rotators backward, the hip capsule can be incised, allowing access to the hip joint. Subsequently, the hip joint is dislocated and the osteotomy of the femoral neck is performed, followed by the removing of the femoral head. The rest of the operation will essentially take place in the same manner as the anterior approach. During closure, the capsule is closed and the short external rotators are sutured back at their insertion site.

Supplemental Table 1
Mean Goutallier Scores for Muscle Atrophy.

Muscles	DAA (N = 22)	PLA (N = 23)	*P*-Value
Gluteus minimus			
Preoperative	1.62 (0.92)	1.42 (1.21)	
Postoperative	1.71 (0.85)	1.29 (1.20)	.20
P-value	.32	.32	
Gluteus medius			
Preoperative	0.71 (0.71)	0.67 (0.64)	
Postoperative	0.62 (0.67)	0.67 (0.64)	.54
P-value	.16	1.00	
Gluteus maximus			
Preoperative	1.05 (0.81)	1.29 (0.69)	
Postoperative	1.10 (0.77)	1.29 (0.69)	.19
P-value	.32	1.00	
Tensor fascia latae			
Preoperative	1.24 (0.77)	1.08 (0.58)	
Postoperative	1.62 (0.87)	1.13 (0.61)	.03
P-value	.003	.32	
Rectus femoris			
Preoperative	0.10 (0.30)	0.08 (0.28)	
Postoperative	0.10 (0.30)	0.08 (0.28)	.96
P-value	1.00	1.00	
Sartorius			
Preoperative	0.14 (0.48)	0.21 (0.51)	
Postoperative	0.14 (0.48)	0.17 (0.38)	.46
P-value	1.00	.32	
Iliacus			
Preoperative	0.00 (0.00)	0.04 (0.20)	
Postoperative	0.05 (0.22)	0.04 (0.20)	.98
P-value	.32	1.00	
Psoas			
Preoperative	0.00 (0.00)	0.04 (0.20)	
Postoperative	0.19 (0.87)	0.04 (0.20)	.95
P-value	.32	1.00	
Quadratus femoris			
Preoperative	0.20 (0.52)	0.38 (0.71)	
Postoperative	0.20 (0.41)	0.54 (0.83)	.09
P-value	1.00	.25	
Piriformis			
Preoperative	0.10 (0.30)	0.13 (0.34)	
Postoperative	1.38 (0.97)	2.00 (1.62)	.15
P-value	<.001	<.001	
Obturator internus			
Preoperative	0.14 (0.36)	0.21 (0.42)	
Postoperative	1.81 (0.93)	2.57 (1.38)	<.001
P-value	<.001	<.001	
Obturator externus			
Preoperative	0.14 (0.36)	0.21 (0.42)	
Postoperative	0.71 (0.78)	2.00 (0.93)	.01
P-value	.006	<.001	

Data presented as mean (SD).
DAA, direct anterior approach; PLA, posterolateral approach.