Prognostics of recovery in hip fracture patients

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Part I

The anterior approach for arthroplasty

Chapter 2

Surgical approaches for hemiarthroplasty: a meta-analysis

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Abstract

Background: The lateral approach (LA), posterior approach (PA), and anterior approach (AA) are conventional surgical access routes for hemiarthroplasty in proximal femoral fractures. This meta-analysis assesses and compares the outcomes and attempts to identify the best approach for hemiarthroplasty in the treatment of proximal femoral fractures.
Methods: An electronic search was performed from inception to October 25, 2017, for comparative studies including at least 2 of the conventional approaches. Outcomes including operation time, surgical blood loss, perioperative fractures, wound infections, dislocations, and hospital length of stay were plotted in forest plots.
Results: Twenty-one eligible studies were selected including 3 randomized, controlled trials, 7 prospective and 11 retrospective cohort studies. The odds ratio (OR) for dislocations was significantly higher for the PA compared with the AA (OR, 2.61; 95% confidence interval [CI], 1.26 to 5.43; P = .01) and the LA (OR, 2.90; 95% CI, 1.63 to 5.14; P = .0003). The PA had a higher risk of reoperation compared to the AA (OR, 1.25; 95% CI, 1.12 to 1.41; P < .0001). No significant differences were found concerning perioperative fractures, wound infections, and hospital length of stay. Some studies suggest a better short-term functional outcome using the AA compared to the PA.
Conclusion: The PA for hemiarthroplasty in proximal femoral fractures poses an increased risk of dislocation and reoperation compared to the LA and AA. There are no evident advantages of the PA and its routine use for fracture-related hemiarthroplasty should be questioned.

Introduction

The proximal femoral fracture is one of the commonest fractures in the older population, with a remaining lifetime risk of more than 10% in men and 20% in women over the age of 50.[1] Femoral neck fractures constitute more than half of these fractures, with displacement of the femoral head fragment in nearly 70%.[2] The displacement of the femoral head is associated with an increased risk of femoral head necrosis due to a disrupted blood flow at the femoral neck, delayed or nonunion and failure of internal fixation devices.[3] For this reason, displaced femoral neck fractures in older patients are often treated with hemiarthroplasty.[3] Replacement of the femoral head and neck with a hemiarthroplasty enables early mobilization which is desirable in older patients as prolonged rehabilitation is associated with high morbidity and mortality rates and increased healthcare costs.[3-5] The surgical approach used for hemiarthroplasty is expected to affect the treatment outcomes. Outcome differences have been described for complications such as dislocations, performance in daily activities and quality of life after the procedure, and the learning curve for surgeons.[6-11]

Three conventional approaches for hemiarthroplasty have been described since the 20th century with only slight modifications over time.[12-17] The lateral approach (LA) includes the lateral, direct lateral, straight lateral, omega lateral, Hardinge, Gammer, the McFarland and Osborne, transgluteal or transtrochanteric approach, and the anterolateral approach, also known as the Watson-Jones procedure.[18, 19] The LA requires (partial) separation and/or retraction of the insertion of the gluteus medius muscle for an adequate exposure of the capsule. In this approach, the distal aponeurotic insertion may be bisected, or a longitudinally trochanteric osteotomy may be performed.[19-21] In variations of the LA, the fibers of the gluteus medius muscle may be split with or without preservation of the vastogluteal continuity. In the anterolateral approach, an intermuscular plane is attained by anterior retraction or longitudinal division of the tensor fascia latae and posterior retraction of the gluteus medius muscle.[9, 22]

The posterior approach (PA) includes the true posterior approach, the posterolateral, back, dorsal, Moore and Southern approaches. It involves a longitudinal division of the gluteus maximus muscle along the fibers with detachment of the short external rotators, with or without preservation of the piriformis tendon for an adequate exposure of the hip joint.[20, 21, 23, 24]

The anterior approach (AA) includes the direct anterior or the true anterior, the Smith-Petersen, the anterior supine intermuscular, and the anterior minimal invasive surgery.[25] The AA uses the intermuscular plane between the sartorius, rectus femoris, and tensor fasciae latae for an adequate exposure of the anterior capsule.[23, 26]

Although outcomes of these approaches have been compared in numerous studies, none of the approaches has been identified as superior. The choice of a specific approach often seems solely to depend on the personal experience and preference of the surgeon, instead of evidence-based guidelines or protocols.[26, 27] Most surgeons are trained predominantly in one specific approach. The aim of this meta-analysis is to summarize the data of recent comparative studies on the outcomes of the 3 commonly used surgical approaches for hemiarthroplasty in the treatment of proximal femoral fractures, in an attempt to identify the preferable approach for treatment of displaced femoral neck fracture in the older patient.

Material and methods

This study was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement guidelines.[28] No study protocol was published before the electronic search was conducted.

Search strategy
An electronic search was performed in PubMed, Embase, Web of Science, the Cochrane Central Register of Controlled Trials, and the Cochrane Database of Systematic Reviews for studies comparing at least 2 of the conventional approaches (LA, PA, AA) up to October 25, 2017. Studies reporting outcomes of a single approach were deemed to be of insufficient comparative nature and unfit for this review. The electronic search strategy was developed in collaboration with an experienced medical librarian and edited for each specific electronic database. The search included exploded MeSH terms and keywords for hip fracture patients treated with hemiarthroplasty. The exact search strategy is presented in Appendix A.

Study selection
Two reviewers independently screened the titles and abstracts of all identified articles for eligibility using the "Covidence systematic review software" (Veritas Health Innovation, Melbourne, Australia). The full-text articles of the potentially relevant studies were read and eligibility for our review's purposes was agreed upon by the 2 reviewers. Any disagreements in the study selection process were resolved through discussion, if necessary with a third reviewer, until consensus was reached. The reference lists of all selected studies were screened for additional relevant citations that were not identified in the electronic search.

We included all randomized and observational studies reporting at least on 1 quantifiable outcome measure of at least 2 of the 3 approaches (LA, PA, AA) for hemiarthroplasty in hip fracture patients. All studies with one or more of the following characteristics were excluded:
- Studies published before 2000, to reflect the current state-of-the-art surgical instruments, materials and methods (other than the approach), healthcare guidelines, and rehabilitation.
- Studies without original data such as reviews and studies reporting on the same dataset without original or relevant results, in which case the most applicable study was included.
- Meeting abstracts, case reports, or studies including fewer than 20 patients.
- Studies on patients with predominantly nontraumatic indications for surgery such as arthrosis.

- Studies on patient groups with a specific comorbidity only.
- Studies including total hip arthroplasty and resurfacing surgery, as these procedures require different prostheses and surgical exposure of the hip.
- Studies on cadavers.
- Studies published and only available in languages other than English.

Data extraction

Data from the selected studies were extracted independently by the 2 reviewers. The study characteristics included the first author, year of publication, country, study design; the number, age, and sex of included patients per surgical approach, and duration of patient follow-up. Outcome measures included the operation time, surgical blood loss, hospital length of stay, incidence of perioperative fractures, wound infections, dislocations, reoperations, postoperative pain, functionality, and quality of life. Extracted raw data of the treatment outcomes can be found in Appendix B. Reported data were used to calculate percentages, incidences, and cumulative means. When incidence numbers were not reported, it was derived and calculated from the article data (such as incidence percentages) when possible. Outcome data reported as median value and range were converted to an estimated mean and standard deviation using the method described by Hozo et al.[29] Differences in the extracted data by the 2 reviewers were resolved by discussion.

Quality assessment

The methodological quality of the selected studies was independently assessed by the 2 reviewers. The 5-item revised tool for Risk of Bias in randomized trials (RoB 2.0)was used to score the risk of bias for all randomized, controlled trials (RCTs).[30, 31] Each item was scored using a 3-point scale corresponding with low risk of bias, some concerns about bias and high risk of bias in domains of the study design, and reported outcomes.

For nonrandomized studies, the 7-item Risk Of Bias in Nonrandomized Studies - of Interventions (ROBINS-I) tool was used.[32] A bias risk score (corresponding with low risk, moderate risk, serious risk, or critical risk of bias, or no available information) was assigned for domains of bias in the preintervention, at-intervention, and postintervention phase of the study.[32]

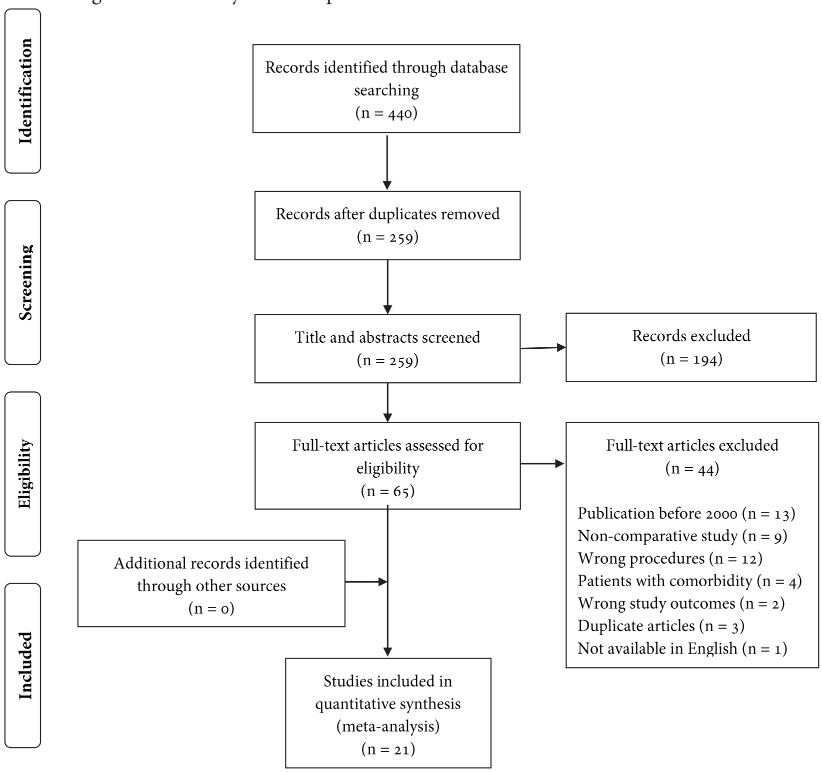
Statistical analysis

Outcome data were pooled if the study population and outcome definitions were similar. Meta-analysis was performed in Review Manager (RevMan) version 5.3 using a random effects model. To confirm the results, the meta-analyses were repeated with only the prospective studies (leaving out the retrospective studies). For the dichotomous outcome data, odds ratios (OR) with 95% confidence interval (CI) were calculated, and continuous outcome data were summarized as mean difference and corresponding 95% CI. In the forest plots, the solid squares denote the Peto OR of each individual study, the horizontal lines represent the 95% confidence intervals (CI), and the diamond denotes the cumulative Peto OR.[33] Statistical heterogeneity across studies was assessed using both the chi-squared test with $P < .10$ regarded as significant, and the I^2 statistic assuming heterogeneity if $I^2 > 50\%$.[34]

Results

The electronic search yielded 440 articles from PubMed (n = 146), Embase (n = 155), Web of Science (n = 94), the Cochrane Database of Systematic Reviews (n = 22), and Cochrane Central Register of Controlled Trials (n = 23). And 259 articles remained after removal of obvious duplicates. After screening titles and abstracts, 194 articles were excluded based on inclusion and exclusion criteria. Another 44 articles were excluded after assessment of the full-text article, leaving 21 articles (n = 61,487 patients) for analysis in this review. One meta-analysis including recent literature was found.[35] No additional relevant studies were found in the reference lists of the included studies. The study selection process is presented in Figure 1.

Figure 1. Flow diagram of the study selection process.



Study characteristics

The 21 selected studies included 3 RCTs (n = 321 patients) and 18 nonrandomized comparative cohort studies of which 7 were prospective (n = 1798 patients) and 11 retrospective (n = 59,368 patients). Nineteen studies evaluated 2 of the 3 approaches, 5 comparing the AA with the PA[11, 23, 36-38], 11 the LA with the PA[7, 8, 10, 20, 21, 24, 27, 39-42] and 3 studies compared the AA with the LA[26, 43, 44]. Two studies included all 3 approaches.[45, 46] The mean age of the study populations ranged from 63 to 88 years and 58 to 92% of the patients were female. The follow-up period varied between 1 and 96 months. The study characteristics are listed in Table 1.

Table 1. Characteristics of included studies, by study design.

Author (publication year)	Country	Sample size per approach			Mean age	Sex (%F)	Follow-up (months)
		AA	LA	PA			
Randomized Controlled Trials							
Auffarth (2011)[26]	Austria	24	24	-	83.2	79	6
Parker (2015)[20]	UK	-	108	108	84.0*	92	12
Renken (2012)[44]	Germany	30	27	-	84.0*	88*	1
Prospective Cohort Studies							
Baba (2013)[23]	Japan	40	-	39	75.8*	83	36
Enocson (2008)[27]	Sweden	-	431	308	84.0	80	27.6 (mean)*
Langlois (2015)[36]	France	38	-	44	85.4*	74	21 (SD ±5.0)
Mukka (2016)[21]	Sweden	-	101	83	84.4	70	12
Sayed-Noor (2016)[39]	Sweden	-	24	24	83.0*	81	12
Svenoy (2017)[42]	Norway	-	397	186	82.8	74	12
Tsukada (2010)[37]	Japan	44	-	39	81.1*	82	12
Retrospective Cohort Studies							
Abram (2015)[40]	UK	-	753	54	83.0	71	3-71 (range)
Biber (2012)[24]	Germany	-	217	487	80.4	70	NA
Bush (2007)[38]	USA	186	-	199	79.8	73	6
Carlson (2017)[43]	USA	85	75	-	82.8*	60*	6
Kristensen (2017)[8]	Norway	-	18918	1990	83.0	73	96
Leonardsson (2016)[7]	Nor/Swe	-	1140	978	85.0	74	6-18 (range)
Ozan (2016)[10]	Turkey	-	86	147	78.6*	58	17.1 (mean)*
Pala (2016)[11]	Italy	55	-	54	88.0	80	6
Rogmark (2014)[41]	Sweden	-	20519	11522	84.0	72	32.4*
Sierra (2006)[46]	USA	1432	125	245	63.0	NA	12
Trinh (2015)[45]	USA	31	41	29	80.7	NA	3.7 (mean)*

AA Anterior Approach, LA Lateral Approach, PA Posterior Approach, y years, F female, NA not available, SD Standard Deviation. *Derived and calculated from article data.

Quality assessment

Some risk of bias was present in all studies, as shown in Appendix C. For 2 of the RCTs, a high risk was considered to be present due to 'missing outcome data' (Appendix table C. 1). The non-randomized cohort studies had on average good quality with a moderate risk of confounding in all retrospective studies (Appendix table C. 2). Four of the 7 prospective cohort studies had relatively small sample sizes. Most prospective studies had no blinding of outcome assessments, meaning there was a risk of detection and observer bias in their outcomes. Most of the studies had dislocation rate as the primary outcome, while the secondary outcomes in these studies were often poorly defined.

Eleven studies were retrospective observational studies susceptible to forms of bias inherent to this study design, such as confirmation bias. Although we only included studies with the predominant reason for hemiarthroplasty being traumatic hip fractures in this review, 3 retrospective studies also included a small number of nontraumatic patients.[7, 11, 46]

Surgical outcomes

Operation time and surgical blood loss

Eleven studies reported the operation time of 2 approaches.[8, 11, 20, 21, 23, 26, 36, 37, 42-44] The study by Parker et al. could not be included in the meta-analysis because no standard deviations were reported. The meta-analyses showed no statistically significant difference in the mean operation time when comparing the PA with the AA (mean difference = 3.0 minutes; 95% CI, -8.5 to 14.5; p = 0.61; Fig. 2A) or the LA with the AA (mean difference = -6.5 minutes; 95% CI, -17.8 to 4.7; p = 0.25; Fig. 2C). The difference in operation time for the PA compared to the LA was borderline significant (mean difference = 10.0 minutes; 95% CI, -20.5 to 0.5; p=0.06; Fig. 2B). Parker et al. reported no significant difference in operation time between the LA and the PA.

Ten studies compared surgical blood loss in various ways, including estimated and measured intraoperative blood loss in milliliters, centiliters, and grams, postoperative drop in hemoglobin blood level, transfusion rates, and hematoma formation.[11, 20, 21, 23, 24, 26, 36, 37, 43, 44]

Carlson et al. reported a significant difference in the hemoglobin before and after surgery in favor of the AA vs the LA. This was not evident from the other studies and insufficient data was available for a meta-analysis.[26, 44] Pala et al. reported less surgical blood loss (in centilitres), but a contradicting and significantly larger drop in postoperative haemoglobin levels for the AA than for the PA. Biber et al. reported significantly more postoperative haematoma formation in the LA compared to the PA (p = 0.001) while Mukka et al. and Parker et al. reported no differences in the average surgical blood loss and transfusion rates.[11, 20, 21, 24]

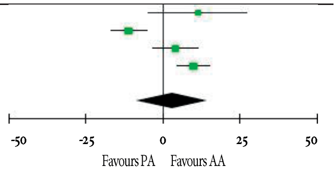
Figure 2. Forest plots comparing the operation time in minutes for (A) the Posterior Approach vs the Anterior Approach, (B) for the Posterior Approach vs the Lateral Approach and (C) for the Lateral Approach vs the Anterior Approach.

(A)

Study	Posterior approach Mean	SD	Total	Anterior approach Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Baba 2013	76.7	33.0	39	65.3	39.0	40	18.8%	11.40 [-4.52, 27.32]
Langlois 2015	54.0	15.0	44	65.0	12.0	38	27.3%	-11.00 [-16.85, -5.15]
Tsukada 2010	79.3	15.2	39	75.1	19.2	44	26.2%	4.20 [-3.21, 11.61]
Pala 2016	57.0	12.5	54	47.0	15.0	55	27.7%	10.00 [4.82, 15.18]
Total (95% CI)			**176**			**177**	**100.0%**	**3.01 [-8.50, 14.52]**

Heterogeneity: $Tau^2 = 117.48$; $Chi^2 = 29.82$, df = 3 ($P < 0.00001$); $I^2 = 90\%$

Test for overall effect: Z = 0.51 (P = 0.61)

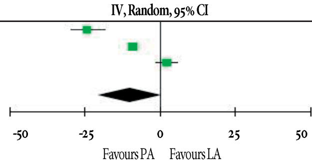


(B)

Study	Posterior approach Mean	SD	Total	Lateral approach Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Mukka 2016	66.0	18.0	83	90.0	21.0	101	31.6%	-24.00 [-29.64, -18.36]
Kristensen 2017	67.0	21.0	1990	76.0	25.0	18918	34.8%	-9.00 [-9.99, -8.01]
Svenoy 2017	69.2	20.0	186	66.9	19.0	397	33.6%	2.30 [-1.13, 5.73]
Total (95% CI)			**2259**			**19416**	**100.0%**	**-9.95 [-20.33, 0.44]**

Heterogeneity: $Tau^2 = 80.46$; $Chi^2 = 68.13$, df = 2 ($P < 0.00001$); $I^2 = 97\%$

Test for overall effect: Z = 1.88 (P = 0.06)

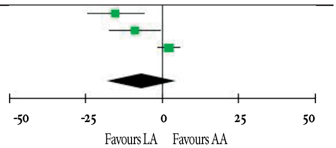


(C)

Study	Lateral approach Mean	SD	Total	Anterior approach Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Auffarth 2011	65.3	11.75	24	80.4	19.5	24	30.8%	-15.10 [-24.21, -5.99]
Remken 2012	64.8	17.1	27	73.6	14.4	30	32.0%	-8.80 [-17.06, -0.54]
Carlson 2017	45.3	8.8	75	42.9	13.9	85	37.2%	2.40 [-1.16, 5.96]
Total (95% CI)			**126**			**139**	**100.0%**	**-6.57 [-17.81, 4.66]**

Heterogeneity: $Tau^2 = 84.97$; $Chi^2 = 16.12$, df = 2 ($P = 0.0003$); $I^2 = 88\%$

Test for overall effect: Z = 1.15 (P = 0.25)



SD, standard deviation; CI, confidence interval.

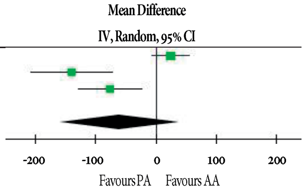
Only 3 studies reported a quantitative measure of mass or volume that could be converted to millilitres of blood loss, to enable a meta-analysis for the PA vs the AA (Fig. 3).[11, 23, 37] No significant difference was observed (mean difference, -60 millilitres; 95% CI, -160 to 39; p = 0.23).

The statistical heterogeneity observed in the outcomes operation time and blood loss between the studies included in these meta-analyses may be attributable to differences in the experience of the surgeons between the studies. In some prospective studies, the patients were only operated by specific surgeons with experience in the used approach.[11, 21] In other studies, surgeons alternated both approaches based on the patient allocation.[23, 36, 37] Both approaches studied by Langlois et al. were performed by unsupervised surgeons in training. Exclusion of this study from the meta-analysis resulted in a comparison with more homogenous study results ($Chi^2 = 1.73$, df = 2, P = .42, $I^2 = 0\%$) and a mean difference in operation time of 8.3 minutes in favour of the AA compared to the PA (95% CI, 4.2 to 12.4; $p < .0001$). Similar methodological reasons for outliers could not be identified for the operation time of the PA compared to the LA and blood loss, although differences in the surgeons' experience between these studies cannot be excluded.

Figure 3. Forest plot comparing surgical blood loss for the Posterior Approach vs the Anterior Approach.

	Posterior approach			Anterior approach				Mean Difference
Study	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Baba 2013	146.0	56.0	39	121.0	82.0	40	35.4%	25.00 [-5.90, 55.90]
Tsukada 2010	230.0	114.9	39	370.1	192.1	44	31.4%	-140.10 [-207.35, -72.85]
Pala 2016	213.0	150.0	54	289.0	130.0	55	33.2%	-76.00 [-128.74, -23.26]
Total (95% CI)			**132**			**139**	**100.0%**	**-60.36 [-159.67, 38.95]**

Heterogeneity: $Tau^2 = 7004.27$; $Chi^2 = 24.73$, $df = 2$ ($P < 0.00001$); $I^2 = 92\%$
Test for overall effect: $Z = 1.19$ ($P = 0.23$)



SD, standard deviation; CI, confidence interval.

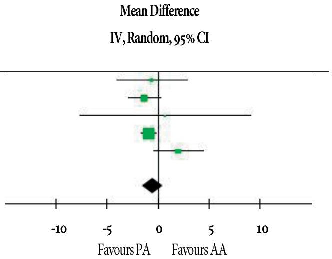
Hospital length of stay

Only Bush and Wilson found a statistically significant difference in the admission time between the PA and AA, the 5 other studies did not.[11, 20, 23, 36, 37] Comparing the pooled results for hospital length of stay time, the PA and AA showed no significant difference (mean difference, -0.54 days; 95% CI, -1.55 to 0.47; p = .29; Fig. 4). Parker et al. compared the hospital length of stay between the PA and LA (mean difference, 1.8 days; p = .40). Carlson et al. reported a significantly shorter hospital length of stay for the AA compared to the LA (mean difference 2.7 days; p < .01).

Figure 4. Forest plot comparing the hospital length of stay for the Posterior Approach vs the Anterior Approach.

	Posterior approach			Anterior approach				Mean Difference
Study	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Baba 2013	29.3	10.25	39	29.9	4.0	40	7.7%	-0.60 [-4.05, 2.85]
Langlois 2015	8.7	4.0	44	10.0	3.3	38	26.0%	-1.30 [-2.88, 0.28]
Tsukada 2010	36.1	21.0	39	35.4	17.4	44	1.4%	0.70 [-7.66, 9.06]
Bush 2007	6.41	3.52	199	7.28	3.98	186	51.0%	-0.87 [-1.62, -0.12]
Pala 2016	14.0	6.75	54	12.0	6.25	55	13.8%	2.00 [-0.44, 4.44]
Total (95% CI)			**375**			**363**	**100.0%**	**-0.54 [-1.55, 0.47]**

Heterogeneity: $Tau^2 = 0.38$; $Chi^2 = 5.55$, $df = 4$ ($P = 0.24$); $I^2 = 28\%$
Test for overall effect: $Z = 1.05$ ($P = 0.29$)



SD, standard deviation; CI, confidence interval.

Complications

Perioperative fractures

One of 13 studies that reported the incidence of perioperative fractures observed that perioperative fractures occurred significantly more often in patients operated using the LA compared to the PA

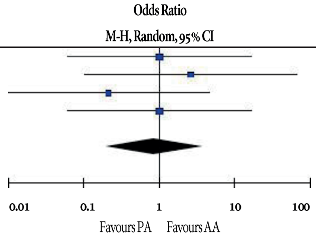
(OR, 1.5; 95% CI, 1.1 to 2.0; p = .03), but this study did not report the patient numbers and could therefore not be included in the meta-analysis.[41] No statistically significant differences were found after pooling data of 4 studies[11, 23, 36, 37] that compared the PA and the AA (OR, 0.87; 95% CI, 0.20 to 3.82; p = .85; Fig. 5A), 5 studies[7, 20, 21, 24, 42] that analyzed the PA and the LA (OR, 1.07; 95% CI, 0.51 to 2.22; p = .87; Fig. 5B) and 3 studies[26, 43, 44] that compared the LA with the AA (OR, 1.13; 95% CI, 0.26 to 4.87; p = .87; Fig. 5C).

Figure 5. Forest plots comparing the incidence of perioperative fractures for (A) the Posterior Approach vs the Anterior Approach, (B) for the Posterior Approach vs the Lateral Approach and (C) for the Lateral Approach vs the Anterior Approach.

(A)

	Posterior approach		Anterior approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Baba 2013	1	39	1	40	27.8%	1.03 [0.06, 17.01]
Langlois 2015	1	44	0	38	21.0%	2.66 [0.11, 67.11]
Tsukada 2010	0	39	2	44	23.3%	0.22 [0.01, 4.62]
Pala 2016	1	54	1	55	28.0%	1.02 [0.06, 16.71]
Total (95% CI)		**176**		**177**	**100.0%**	**0.87 [0.20, 3.82]**
Total events	3		4			

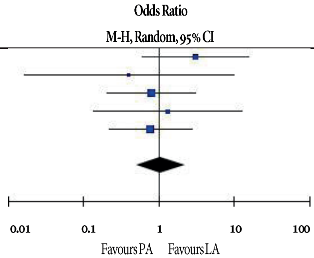
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.29$, df = 3 (P = 0.73); $I^2 = 0\%$
Test for overall effect: Z = 0.19 (P = 0.85)



(B)

	Posterior approach		Anterior approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Parker 2015	6	108	2	108	20.5%	3.12 [0.61, 15.80]
Mukka 2016	0	83	1	102	5.2%	0.41 [0.02, 10.08]
Svenoy 2017	3	186	8	397	30.2%	0.80 [0.21, 3.04]
Biber 2012	3	487	1	217	10.5%	1.34 [0.14, 12.94]
Leonardsson 2016	4	978	6	1140	33.6%	0.78 [0.22, 2.76]
Total (95% CI)		**1842**		**1964**	**100.0%**	**1.07 [0.51, 2.22]**
Total events	16		18			

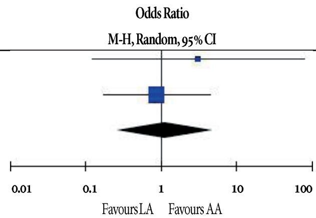
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 2.49$, df = 4 (P = 0.65); $I^2 = 0\%$
Test for overall effect: Z = 0.17 (P = 0.87)



(C)

	Lateral approach		Anterior approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Auffarth 2011	1	24	0	24	20.1%	3.13 [0.12, 80.68]
Renken 2012	0	27	0	30		Not estimable
Carlson 2017	3	85	3	75	79.9%	0.88 [0.17, 4.49]
Total (95% CI)		**136**		**129**	**100.0%**	**1.13 [0.26, 4.87]**
Total events	4		3			

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.47$, df = 1 (P = 0.49); $I^2 = 0\%$
Test for overall effect: Z = 0.17 (P = 0.87)



SD, standard deviation; CI, confidence interval.

Wound infections

Two of 3 studies comparing the PA with the AA reported no cases of wound infections in either group, so no meta-analysis could be performed. The third study reported no significant difference.[23, 36, 37] None of the 7 studies that compared wound infections between the PA and the LA reported a significant difference in wound infections.[7, 10, 20, 21, 24, 41, 42] Rogmark et al. reported an OR of 0.8 (95% CI, 0.7 to 1.0; p = .05) but no patient numbers, and could therefore not be included in the meta-analysis. The pooled incidence indicated no difference in the risk of infections between the PA vs the LA (OR, 1.23; 95% CI, 0.82 to 1.84; p = .31; Fig. 6A). No significant difference in infection rate was found in the individual studies and in the meta-analysis comparing the LA and the AA (OR, 1.26; 95% CI, 0.24 to 6.67; p = .78; Fig. 6B).[26, 43, 44]

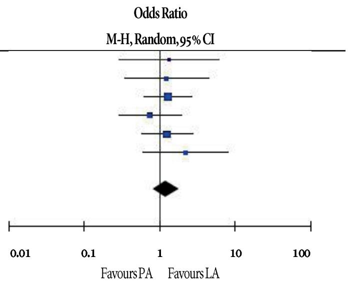
Figure 6. Forest plot comparing the incidence of wound infections for (A) the Posterior Approach vs the Lateral Approach and (B) for the Lateral Approach vs the Anterior Approach.

(A)

	Posterior approach		Lateral approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Parker 2015	4	108	3	108	7.0%	1.35 [0.29, 6.16]
Mukka 2016	5	83	5	102	9.9%	1.24 [0.35, 4.45]
Svenoy 2017	12	186	20	397	29.7%	1.30 [0.62, 2.72]
Biber 2012	12	487	7	217	18.0%	0.76 [0.29, 1.95]
Leonardsson 2016	13	978	12	1140	25.9%	1.27 [0.58, 2.79]
Ozan 2016	11	147	3	86	9.5%	2.24 [0.61, 8.26]
Total (95% CI)		**1989**		**2050**	**100.0%**	**1.23 [0.82, 1.84]**
Total events	57		50			

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.86$, df = 5 (P = 0.87); $I^2 = 0\%$

Test for overall effect: Z = 1.01 (P = 0.31)

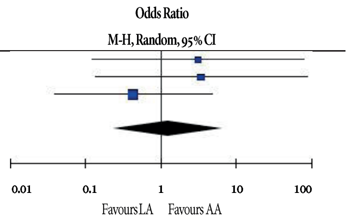


(B)

	Lateral approach		Anterior approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Auffarth 2011	1	24	0	24	26.3%	3.13 [0.12, 80.68]
Renken 2012	1	27	0	30	26.4%	3.45 [0.13, 88.40]
Carlson 2017	1	85	2	75	47.3%	0.43 [0.04, 4.89]
Total (95% CI)		**136**		**129**	**100.0%**	**1.26 [0.24, 6.67]**
Total events	3		2			

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.42$, df = 2 (P = 0.49); $I^2 = 0\%$

Test for overall effect: Z = 0.27 (P = 0.78)



SD, standard deviation; CI, confidence interval.v

Dislocations

Nineteen out of the 21 included studies reported the dislocation incidence after surgery. Fifteen of these compared the PA with one of the other approaches (5 with the AA[11, 23, 36-38], 10 with the LA, of which 9 available for the meta-analysis[7, 10, 20, 21, 24, 27, 39-42] and 2 compared all 3 approaches[45, 46]). Two studies compared the LA with the AA of which one reported no cases of dislocations in either group.[43, 44]

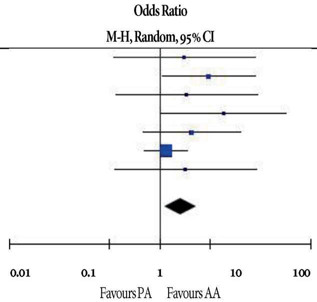
In the meta-analyses, the incidence of dislocations after the PA was higher than after the AA (OR, 2.61; 95% CI, 1.26 to 5.43; p = .01; Fig. 7A) and after the LA (OR, 2.90; 95% CI, 1.63 to 5.14; p = .0003; Fig. 7B). Four studies compared the dislocation rate between the LA and AA.[43-46] In the meta-analysis an OR of 1.87 (95% CI, 0.77 to 4.55; p = .17; Fig. 7C) was found for dislocation after the LA compared to the AA.

Figure 7. Forest plots comparing the dislocation rate for (A) the Posterior Approach vs the Anterior Approach, (B) for the Posterior Approach vs the Lateral Approach and (C) for the Lateral Approach vs the Anterior Approach.

(A)

	Posterior approach		Anterior approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Baba 2013	1	39	0	40	5.1%	3.16 [0.12, 79.85]
Langlois 2015	9	44	1	38	11.9%	9.51 [1.15, 79.03]
Tsukada 2010	1	39	0	44	5.1%	3.47 [0.14, 87.62]
Bush 2007	9	199	0	186	6.6%	18.60 [1.07, 321.88]
Pala 2016	4	54	1	55	10.8%	4.32 [0.47, 39.97]
Sierra 2006	5	245	22	1432	55.5%	1.34 [0.50, 3.56]
Trinh 2015	1	29	0	31	5.1%	3.32 [0.13, 84.70]
Total (95% CI)		**649**		**1826**	**100.0%**	**2.61 [1.26, 5.43]**
Total events	30		24			

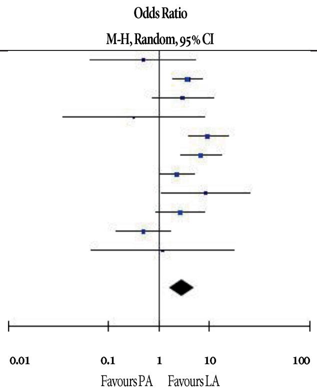
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 5.86$, df = 6 (P = 0.44); $I^2 = 0\%$
Test for overall effect: Z = 2.58 (P = 0.010)



(B)

	Posterior approach		Lateral approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Parker 2015	1	108	2	108	4.3%	0.50 [0.04, 5.55]
Enocson 2008	32	305	13	431	15.2%	3.77 [1.94, 7.31]
Mukka 2016	7	83	3	102	9.0%	3.04 [0.76, 12.14]
Sayed-Noor 2016	0	24	1	24	2.7%	0.32 [0.01, 8.25]
Svenoy 2017	24	186	6	397	12.8%	9.65 [3.87, 24.06]
Abram 2015	7	54	16	753	12.6%	6.86 [2.69, 17.49]
Leonardsson 2016	20	978	10	1140	14.2%	2.36 [1.10, 5.06]
Biber 2012	19	487	1	217	5.7%	8.77 [1.17, 65.93]
Ozan 2016	17	147	4	86	11.0%	2.68 [0.87, 8.25]
Sierra 2006	5	245	5	125	9.9%	0.50 [0.14, 1.76]
Trinh 2015	1	29	0	11	2.6%	1.21 [0.05, 31.95]
Total (95% CI)		**2646**		**3394**	**100.0%**	**2.90 [1.63, 5.14]**
Total events	133		61			

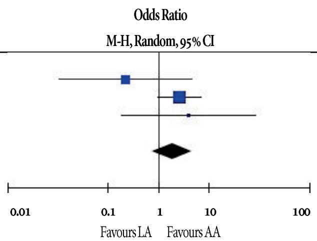
Heterogeneity: $Tau^2 = 0.45$; $Chi^2 = 22.95$, df = 10 (P = 0.01); $I^2 = 56\%$
Test for overall effect: Z = 3.64 (P = 0.0003)



(C)

	Lateral approach		Anterior approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Renken 2012	0	27	0	30		Not estimable
Carlson 2017	0	75	2	85	37.3%	0.22 [0.01, 4.68]
Sierra 2006	5	125	22	1432	54.2%	2.67 [0.99, 7.18]
Trinh 2015	2	41	0	31	8.5%	3.99 [0.18, 86.09]
Total (95% CI)		**268**		**1578**	**100.0%**	**1.87 [0.77, 4.55]**
Total events	7		24			

Heterogeneity: $Chi^2 = 2.61$, df = 2 (P = 0.27); $I^2 = 23\%$
Test for overall effect: Z = 1.38 (P = 0.17)



SD, standard deviation; CI, confidence interval.

Reoperation rate

In the selected studies, reoperations included among others closed and open reduction of dislocations, revision arthroplasties, fixation of perioperative fractures, and capsular repair after repetitive dislocations. Only Langlois et al. compared the reoperation rates of the PA with the AA.[36] No significant differences have been reported in recent literature on the long-term prosthesis survival between the AA and PA.[11, 36]

Rogmark et al. reported a statistically significant difference in the reoperation rate of the PA compared the LA in favour of the LA.[41] The meta-analysis including 4 studies showed a significant result in favour of the LA (OR, 1.25; 95% CI, 1.12 to 1.41; $p < .0001$; Fig. 8A).[7, 20, 21, 41] This result was mostly due to the large number of patients in the study by Rogmark et al., with a weight of more than 90% in the meta-analysis. The meta-analysis comparing the LA with the AA included 3 studies and indicated no significant difference (OR, 1.54; 95% CI, 0.50 to 4.77; $p = .45$; Fig. 8B).[26, 43, 44]

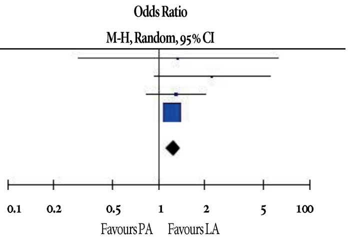
When repeating the meta-analyses including only the studies with a prospective design, the outcomes were similar to those of the meta-analyses that also included the retrospective studies. These outcomes are not included in this publication, but are available upon request.

Figure 8. Forest plot comparing the reoperation rate for (A) the Posterior Approach vs the Lateral Approach and (B) for the Lateral Approach vs the Anterior Approach.

(A)

	Posterior approach		Lateral approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Parker 2015	4	108	3	108	0.6%	1.35 [0.29, 6.16]
Mukka 2016	15	83	9	102	1.7%	2.28 [0.94, 5.52]
Leonardsson 2016	40	978	36	1140	6.2%	1.31 [0.83, 2.07]
Rogmark 2014	477	11999	687	21206	91.6%	1.24 [1.10, 1.39]
Total (95% CI)		**13168**		**22556**	**100.0%**	**1.25 [1.12, 1.41]**
Total events	536		735			

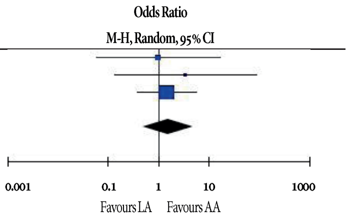
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.85$, $df = 3$ ($P = 0.60$); $I^2 = 0\%$
Test for overall effect: $Z = 3.89$ ($P < 0.0001$)



(B)

	Lateral approach		Anterior approach			Odds Ratio
Study	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Auffarth 2011	1	24	1	24	19.5%	1.00 [0.06, 16.97]
Renken 2012	1	27	0	30	9.2%	3.45 [0.13, 88.40]
Carlson 2017	5	75	4	85	71.3%	1.45 [0.37, 5.60]
Total (95% CI)		**126**		**139**	**100.0%**	**1.54 [0.50, 4.77]**
Total events	7		5			

Heterogeneity: $Chi^2 = 0.34$, $df = 2$ ($P = 0.85$); $I^2 = 0\%$
Test for overall effect: $Z = 0.75$ ($P = 0.45$)



SD, standard deviation; CI, confidence interval.

Patient reported outcomes

Pain

Postoperative pain was rated in 7 studies.[7, 8, 11, 21, 26, 36, 39] Because the studies used different methods including the Visual Analogue Scale, Numeric Rating Scale (NRS) scores, and the use of analgesic medication at various intervals after surgery, the results could not be pooled. Auffarth et al. and Renken et al. both reported significant, contradicting results comparing the AA and LA. Pala et al. reported significantly more pain on the first postoperative days after the AA than after the PA. From day 4 onwards results were similar for the AA and PA.[36] Two other studies compared the long-term pain perception of patients for the LA and the PA, which was significantly better for the PA.[7, 8]

Functionality

Nine studies assessed the patients' functionality using several different Patient Reported Outcome Measures (PROMS), such as the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Barthel Index or the Harris Hip Score (HHS).[8, 21, 23, 26, 36, 37, 39, 43, 44] Four of these studies reported the HHS, but after varying intervals up to one-year after surgery.[21, 26, 37, 39] Therefore, a meta-analysis of these results was not feasible.

Only Tsukada and Wakui reported statistically significant differences in the HHS in favour of the AA compared to the PA after 2 months.[37] However, this difference was no longer significant after 4 months. The benefit in short-term functionality of the AA vs PA was also found in the study of Baba et al., who reported the unaided walking ability measured with a 4-category mobility score after 2 weeks.[23] Similar to the study by Tsukada and Wakui, the reported difference in functionality was no longer significant after 6 months.

Regarding a comparison between the PA and LA, significantly more patients walked with a limp and suffered from a positive Trendelenburg sign after the LA in the study by Sayed-Noor et al. but this study showed no significant difference in the HHS after 12 months.[39] Only Kristensen et al. reported a long-term difference in functionality with a significant difference up to 3 years in favour of the PA over the LA.[8] Only 1 of 3 studies that compared functional outcome between the AA and LA reported a significant difference in the short-term postoperative mobility, in favour of the AA.[26, 43, 44]

Quality of life

Only 3 studies reported on aspects of the patient-reported quality of life such as patient satisfaction or general health-related quality of life measured with the EuroQol-5D.[7, 8, 39] All 3 studies compared the LA with the PA, but only the largest study showed significant differences in the EuroQol-5D in favour of the PA, also after adjusting for confounding variables.[8]

Discussion

This meta-analysis aimed at analyzing the available evidence on compared outcomes after 3 conventional surgical access routes for hemiarthroplasty in proximal femoral fractures, in order to identify the superior surgical approach. It is the first meta-analysis to compare all 3 major groups of approaches with each of the other.

Most notably, many studies had dislocation as primary outcome and compared the PA to either the AA or LA. Statistically significant differences were observed in each comparison with the lowest risk of dislocation after surgery using the AA and highest after use of the PA. The outcome of the meta-analyses is significant for each of the comparisons with the PA, with little heterogeneity in the data. Higher dislocation rates are described in literature regardless of posterior capsule repair and dislocations are the most frequent cause for reoperations and revisions of a hemiarthroplasty.[21, 27] Our meta-analysis for reoperations supports the latter, indicating a higher reoperation risk for the PA compared to the LA.[7] The elevated risk of dislocation after the PA and the associated increased risk of reoperation seem the most apparent of all outcomes studied in this meta-analysis. In this respect, the PA may be regarded as an inferior approach compared to the AA and LA, which pleads against the routine use of this approach for hemiarthroplasty. Especially in older patients, these complications cause significant morbidity. Surgeons in training may want to focus on the AA or LA for regular use in hemiarthroplasty.

The pooled data indicate a shorter operation time with the PA compared to the LA and hint at a shorter operation time for the AA compared to the PA for experienced surgeons. However, large heterogeneity was observed and the clinical relevance in the treatment of femoral neck fractures is questionable. Large statistical heterogeneity was also observed for the surgical blood loss between the studies. These surgical outcomes in general have a strong correlation with the experience of the surgical team[36, 47-49] and with the technical difficulty of the procedure.[11, 37] This stresses that the outcomes of these operations are optimized in the hands of experienced and dedicated surgeons.

Studies report a longer learning curve for the AA, claiming that this procedure is technically more difficult to perform.[11] Consequently, the AA is also associated in some studies with higher risks for complications such as greater trochanteric fractures and nerve damage, more blood loss and a longer operation time in some studies, though this is not evident from our meta-analyses.[11, 36, 37] A shorter hospital length of stay was found for the AA vs the LA.[43] No other significant differences were found based on the available data and pooled analyses for the hospital length of stay, the incidence of wound infections and perioperative fractures.

Data on patient-reported function in several studies could not be pooled because different assessments were used on different time points. However, a review of the data suggests better short-term functional outcomes using the AA compared to the PA.[23, 36, 37] Many studies agree that the apparent functional benefit of the AA compared the other approaches is of major clinical importance.[26, 44, 45] Although no significant long-term differences were reported, a better short-term mobility could be deterministic for the rehabilitation strategy. Patients with a faster recovery can be discharged earlier, which Carlson et al. may indicate with a shorter hospital length of stay after the AA compared to the LA.[45] This could mean an increase in postoperative self-dependence, fewer admissions to rehabilitation homes and a decrease of health-care costs. However, the current findings are inconclusive and more well-designed studies are needed to confirm these assumptions.

Overall complication rates[11, 20, 21, 24, 36] and mortality rates[10, 20, 24, 36, 45] found in recent literature did not report any significant differences correlated to the surgical approach.

Our conclusions in respect to the dislocation rates and functionality are similar to a previous meta-analysis on the anterior approach.[35]

The large Scandinavian surveys suggest a lower postoperative quality of life after the LA compared to the PA, attributed to gluteus medius muscle insufficiency associated with the LA.[7, 8] However, the study by Sayed-Noor et al. indicates that the high prevalence of a Trendelenburg sign and limp does not affect the clinical outcome. The studies by Leonardsson et al. and Kristensen et al. on the postoperative quality of life may have been susceptible to sampling bias, because their methodology excluded a disproportionate number of cognitively impaired patients.[7, 8] Dementia is prevalent in up to 85% percent of the older hip fracture population[50], and is considered a major risk factor for hemiarthroplasty dislocation.[23, 51] In the predominantly older hip fracture patient population, patient-reported outcome measures may be biased towards fitter patients. Kristensen et al. concludes that despite the increased risk for dislocations, the PA results in a favourable quality of life, but this should be specified for mentally competent patients who comprehend their movement restrictions.

Limitations

Only 3 RCTs were eligible for inclusion in this meta-analysis. All other included studies were comparative cohort studies with a moderate risk of bias. Additionally, the retrospective studies included far more patients compared to the prospective studies, weighing heavier in the results of all meta-analyses. However, similarity in the outcomes of the meta-analysis with and without the retrospective studies indicates a degree of reliability for the retrospective methodology to study surgical outcomes.

Besides previously stated causes of the statistical heterogeneity found in the pooled data, differences between the studies were observed regarding the implant type, the ratio of cemented and uncemented arthroplasties, rehabilitation strategies and the length of follow-up period. For our study, we pooled conventional approaches with similar technical and anatomical variations in 3 main approach groups (AA, LA and PA), assuming that the surgical techniques within each of the 3 main groups render similar outcomes. This assumption was not studied and differences in outcomes cannot be ruled out.

Also, differences in the methods of treatment and outcome assessment were observed between the included studies, so that meta-analysis of clinically relevant treatment outcomes such as functionality and postoperative pain could not be performed. Our study pooled the technical and anatomical similar varieties on conventional approaches to form 3 main approach groups (AA, LA and PA). Clinically relevant differences in the treatment outcomes between the surgical techniques within each of the 3 main groups are poorly studied, but can't be ruled out. Such differences for example, have been found in pain and mobility for the anterolateral and direct lateral approach[52], but not for the posterior minimal invasive surgery vs the conventional posterior approach[53].

Finally, only a few studies were available for comparisons with the LA. Given these limitations, more well-designed studies are needed to confirm the findings presented in this meta-analysis. Detailed analyses of national datasets such as the Swedish Hip Arthroplasty Register, the National Joint Registry for England and Wales and the Dutch Hip Fracture Audit could provide additional insight in the treatment outcomes of various approaches.

Conclusions

The PA demonstrates an increased risk of dislocation and re-operation compared to the LA and AA. No advantages of the posterior approach were found that might counterbalance the disadvantage of the increased dislocation risk. Its use for fracture related hemiarthroplasty is therefore questionable. Based on the current literature, the LA and AA have comparable outcomes in terms of surgical outcomes and complications, so that one cannot be preferred over the other. The AA may be related to faster recovery in terms of better short-term functional outcomes compared to the PA and earlier discharged compared to the LA. High quality comparative studies are needed to further substantiate the preferred anatomical route for hemiarthroplasty in older femoral neck fracture patients.

Appendices

Appendix A

Search strategy (PubMed)

((“Hip Fractures”[Mesh] OR “hip fracture”[tw] OR “hip fractures”[tw] OR “femoral neck fracture”[tw] OR “femoral neck fractures”[tw] OR “collum fracture”[tw] OR “collum fractures”[tw] OR “collum femoris fracture”[tw] OR “collum femoris fractures”[tw] OR “proximal femur fracture”[tw] OR “proximal femur fractures”[tw] OR “intertrochanteric fracture”[tw] OR “intertrochanteric fractures”[tw] OR “inter trochanteric fracture”[tw] OR “inter trochanteric fractures”[tw] OR “subtrochanteric fracture”[tw] OR “subtrochanteric fractures”[tw] OR “sub trochanteric fracture”[tw] OR “sub trochanteric fractures”[tw]) AND (“Hip Prosthesis”[Mesh] OR “Arthroplasty, Replacement, Hip”[Mesh] OR “prosthesis”[tw] OR prosthe*[tw] OR “arthroplasty”[tw] OR “hemiarthroplasty”[tw] OR arthroplast*[tw] OR hemiarthroplast*[tw] OR “BHH”[tw])) AND (((“anterior”[tw] OR anterior*[tw] OR “anterior approach”[tw] OR “true anterior”[tw] OR “direct anterior approach”[tw] OR “DAA”[tw] OR “smith-petersen”[tw] OR “smith petersen”[tw] OR “smithpetersen”[tw] OR “ASI”[tw] OR “AMIS”[tw]) AND (“anterolateral”[tw] OR “antero lateral”[tw] OR anterolateral*[tw] OR antero lateral*[tw] OR “Watson-Jones”[tw] OR “Watson Jones”[tw] OR “watsonjones”[tw])) OR ((“anterior”[tw] OR anterior*[tw] OR “anterior approach”[tw] OR “true anterior”[tw] OR “direct anterior approach”[tw] OR “DAA”[tw] OR “smith-petersen”[tw] OR “smith petersen”[tw] OR “smithpetersen”[tw] OR “ASI”[tw] OR “AMIS”[tw]) AND (“lateral”[tw] OR lateral*[tw] OR “lateral approach”[tw] OR “direct lateral approach”[tw] OR “Hardinge”[tw] OR “transgluteal”[tw] OR transglutea*[tw] OR “trans gluteal”[tw] OR trans glutea*[tw] OR “transtrochanteric”[tw] OR transtrochanter*[tw] OR “trans trochanteric”[tw] OR trans trochanter*[tw] OR “McFarland and Osborne”[tw])) OR ((“anterior”[tw] OR anterior*[tw] OR “anterior approach”[tw] OR “true anterior”[tw] OR “direct anterior approach”[tw] OR “DAA”[tw] OR “smith-petersen”[tw] OR “smith petersen”[tw] OR “smithpetersen”[tw] OR “ASI”[tw] OR “AMIS”[tw]) AND (“posterior”[tw] OR posterior*[tw] OR “posterolateral”[tw] OR posterolater*[tw] OR “postero lateral”[tw] OR postero lateral*[tw] OR “back”[tw] OR “Moore”[tw] OR “Southern”[tw])) OR ((“anterior”[tw] OR anterior*[tw] OR “anterior approach”[tw] OR “true anterior”[tw] OR “direct anterior approach”[tw] OR “DAA”[tw] OR “smith-petersen”[tw] OR “smith petersen”[tw] OR “smithpetersen”[tw] OR “ASI”[tw] OR “AMIS”[tw]) AND (“minimal invasive”[tw] OR minimal invasiv*[tw] OR “minimally invasive”[tw] OR minimally invasiv*[tw] OR “two-incision”[tw] OR “two incision”[tw] OR two-incision*[tw] OR two incision*[tw] OR “2-incision”[tw] OR “2 incision”[tw] OR 2-incision*[tw] OR 2 incision*[tw] OR “Minimally Invasive Surgical Procedures”[Mesh])) OR ((“anterolateral”[tw] OR “antero lateral”[tw] OR anterolateral*[tw] OR antero lateral*[tw] OR “Watson-Jones”[tw] OR “Watson

Jones"[tw] OR "watsonjones"[tw]) AND ("lateral"[tw] OR lateral*[tw] OR "lateral approach"[tw] OR "direct lateral approach"[tw] OR "Hardinge"[tw] OR "transgluteal"[tw] OR transglutea*[tw] OR "trans gluteal"[tw] OR trans glutea*[tw] OR "transtrochanteric"[tw] OR transtrochanter*[tw] OR "trans trochanteric"[tw] OR trans trochanter*[tw] OR "McFarland and Osborne"[tw])) OR (("anterolateral"[tw] OR "antero lateral"[tw] OR anterolateral*[tw] OR antero lateral*[tw] OR "Watson-Jones"[tw] OR "Watson Jones"[tw] OR "watsonjones"[tw]) AND ("posterior"[tw] OR posterior*[tw] OR "posterolateral"[tw] OR posterolater*[tw] OR "postero lateral"[tw] OR postero lateral*[tw] OR "back"[tw] OR "Moore"[tw] OR "Southern"[tw])) OR (("anterolateral"[tw] OR "antero lateral"[tw] OR anterolateral*[tw] OR antero lateral*[tw] OR "Watson-Jones"[tw] OR "Watson Jones"[tw] OR "watsonjones"[tw]) AND ("minimal invasive"[tw] OR minimal invasiv*[tw] OR "minimally invasive"[tw] OR minimally invasiv*[tw] OR "two-incision"[tw] OR "two incision"[tw] OR two-incision*[tw] OR two incision*[tw] OR "2-incision"[tw] OR "2 incision"[tw] OR 2-incision*[tw] OR 2 incision*[tw] OR "Minimally Invasive Surgical Procedures"[Mesh])) OR (("lateral"[tw] OR lateral*[tw] OR "lateral approach"[tw] OR "direct lateral approach"[tw] OR "Hardinge"[tw] OR "transgluteal"[tw] OR transglutea*[tw] OR "trans gluteal"[tw] OR trans glutea*[tw] OR "transtrochanteric"[tw] OR transtrochanter*[tw] OR "trans trochanteric"[tw] OR trans trochanter*[tw] OR "McFarland and Osborne"[tw]) AND ("posterior"[tw] OR posterior*[tw] OR "posterolateral"[tw] OR posterolater*[tw] OR "postero lateral"[tw] OR postero lateral*[tw] OR "back"[tw] OR "Moore"[tw] OR "Southern"[tw])) OR (("lateral"[tw] OR lateral*[tw] OR "lateral approach"[tw] OR "direct lateral approach"[tw] OR "Hardinge"[tw] OR "transgluteal"[tw] OR transglutea*[tw] OR "trans gluteal"[tw] OR trans glutea*[tw] OR "transtrochanteric"[tw] OR transtrochanter*[tw] OR "trans trochanteric"[tw] OR trans trochanter*[tw] OR "McFarland and Osborne"[tw]) AND ("minimal invasive"[tw] OR minimal invasiv*[tw] OR "minimally invasive"[tw] OR minimally invasiv*[tw] OR "two-incision"[tw] OR "two incision"[tw] OR two-incision*[tw] OR two incision*[tw] OR "2-incision"[tw] OR "2 incision"[tw] OR 2-incision*[tw] OR 2 incision*[tw] OR "Minimally Invasive Surgical Procedures"[Mesh])) OR (("posterior"[tw] OR posterior*[tw] OR "posterolateral"[tw] OR posterolater*[tw] OR "postero lateral"[tw] OR postero lateral*[tw] OR "back"[tw] OR "Moore"[tw] OR "Southern"[tw]) AND ("minimal invasive"[tw] OR minimal invasiv*[tw] OR "minimally invasive"[tw] OR minimally invasiv*[tw] OR "two-incision"[tw] OR "two incision"[tw] OR two-incision*[tw] OR two incision*[tw] OR "2-incision"[tw] OR "2 incision"[tw] OR 2-incision*[tw] OR 2 incision*[tw] OR "Minimally Invasive Surgical Procedures"[Mesh]))) NOT ("Animals"[mesh] NOT "Humans"[mesh]) AND (english[la] OR dutch[la]) NOT ("THA"[ti] OR "total hip"[ti] OR "total hips"[ti])

Appendix B

Raw extracted data of treatment outcomes.

Appendix table B.1 Mean operation time.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Auffarth (2011)	Average operative time (min)	80.4 (45-123; SD ±**19.5**)	65.3 (45-92; SD ±**11.75**)	-	0.022
Renken (2012)	Skin to skin time (min)	73.6 (SD ±14.4)	64.8(SD ±17.1)	-	ns
Carlson (2017)	Length of surgery (min)	42.9 (SD ±13.9)	45.3 (SD ±8.8)	-	*<0.1*
Baba (2013)	Duration of surgery (min)	65.3 (SD ±39)	-	76.7 (SD ±33)	NA
Langlois (2015)	Operative time (min)	65 (SD ±12)	-	54 (SD ±15)	*0.005*
Pala (2016)	Mean surgery time (min)	47 (20-80; SD ±**15**)	-	57 (30-80; SD ±**12.5**)	*0.001*
Tsukada (2010)	Duration of surgery (min)	75.1 (SD ±19.2)	-	79.3 (SD ±15.2)	0.27
Kristensen (2017)	Operation time (min)	-	76 (SD ±25)	67 (SD ±21)	*<0.001*
Mukka (2016)	Surgical time (min)	-	90 (SD ±21)	66 (SD ±18)	NA
Parker (2015)	Operative time (min)	-	53.6	54.0	0.8
Svenoy (2017)	Mean duration of surgery (min)	-	**66.9 (SD ±19)**	69.2 (SD ±20)	NA

Italic font indicates statistical significance (p < .05). Numbers derived and calculated from article data are indicated in bold. AA, anterior approach; LA, lateral approach; PA, posterior approach; SD, standard deviation; ns, not significant; NA, not available.

Appendix table B.2 Mean surgical blood loss.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Auffarth (2011)	Perioperative blood loss (haemoglobin trend)	NA	NA	-	0.30
	Postoperative hematoma (n)	4/24	2/24	-	NA
	Intra- and postoperative transfusions	NA	NA	-	0.21
Renken (2012)	Transfusions during study period (mean)	1.1 (SD ±1.4)	1.7 (SD ±3.5)	-	0.44
	Haemoglobin postop (g/l)	110.5 (SD ±16.3)	105.0 (SD ±15.0)	-	ns
Carlson (2017)	Difference in haemoglobin (g/dL)	2.3 (SD ±1.1)	3.0 (SD ±1.3)	-	*<0.01*
	Transfusions (n)	15/85	18/75	-	0.30
Baba (2013)	Intraoperative blood loss (gr)	121 (SD ±82)	-	146 (SD ±56)	NA

Appendix table B.2 Mean surgical blood loss. (continued)

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Langlois (2015)	Drop in haemoglobin (g/dL)	3.0 (SD ±3.4)	-	3.1 (SD ±3.9)	0.9
	Transfusion required (%)	36	-	42	0.8
Pala (2016)	Mean blood loss in drainage (cc)	289 (80-600; SD **±130**)	- -	213 (0-600; SD **±150**)	*0.06* *0.02*
	Haemoglobin difference preoperative and on the first postoperative day (g/dL)	1.5 (0-5.4)	-	1.9 (0-4)	NA
Tsukada (2010)	Blood loss during surgery (ml)	370.1 (SD ±192.1)	-	230 (SD ±114.9)	*0.0002*
Biber (2012)	Postoperative haematoma (%)	-	5.5 (SD ±3.1)	1.2 (SD ±1.0)	*0.001*
Mukka (2016)	Blood loss (unit NA)	-	254 (SD ±141)	239 (SD ±186)	NA
Parker (2015)	Transfusions n (%)	-	14 (13.2%)	21 (19.8%)	0.3
	Mean units blood transfused		0.19	0.31	0.2

Italic font indicates statistical significance ($p < .05$). Numbers derived and calculated from article data are indicated in bold. AA, anterior approach; LA, lateral approach; PA, posterior approach; SD, standard deviation; ns, not significant; NA, not available.

Appendix table B.3 Fractures.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Auffarth (2011)	Intraoperative femoral shaft fracture	0/24	1/24	-	NA
Carlson (2017)	Periprosthetic fractures	3/85	3/75	-	NA
Baba (2013)	Fractures (femoral greater trochanter and calcar)	1/40	-	1/39	NA
Langlois (2015)	Intraoperative fractures	0/38	-	1/44	NA
Pala (2016)	Periprosthetic fractures	0/55	-	1/54 (1.8%)	NA
	Great trochanter fractures	1/55 (1.8%)	-	0/54	NA
Tsukada (2010)	Greater trochanteric fractures	2/44	-	0/39	NA
Biber (2012)	Perioperative fracture; fractures occurring intraoperatively or early postoperatively	-	0.5% (SD ±0.9)	0.6% (SD ±0.7)	0.80
		-	**1/217**	**3/487**	
Mukka (2016)	Peri-prosthetic fracture	-	1/102	0/83	NA
Leonardsson (2016)	Fracture as a reason for re-operation	-	6/1140 (0.5%)	4/978 (0.4%)	0.7
Parker (2015)	Small operative fracture femur (fracture of the greater trochanter that required no specific treatment)	-	6/108 (5.7%)	1/108 (0.9%)	0.1

Appendix table B.3 Fractures. (continued)

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
	Large operative fracture femur (fracture at the level of the lesser trochanter requiring cerclage wiring)	-	0/108 (0.0%)	1/108 (0.9%)	1.0
	Cumulative small and large fractures	-	**6/108**	**2/108**	
Rogmark (2014)	Periprosthetic fractures as a risk factor for reoperation (HR)	-	1.0	1.5 (1.1-2.0)	*0.03*
Svenoy (2017)	Perioperative fractures	-	3/186 (2%)	8/397 (2%)	0.74

Italic font indicates statistical significance (p < .05). Numbers derived and calculated from article data are indicated in bold. AA, anterior approach; LA, lateral approach; PA, posterior approach; SD, standard deviation; ns, not significant; NA, not available..

Appendix table B.4 Wound infections.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Auffarth (2011)	Deep wound infection	0/24	1/24	-	NA
Carlson (2017)	Periprosthetic infection	1/85	2/75	-	NA
Baba (2013)	Infection of the superficial layer or deep area	0/40	-	0/39	NA
Langlois (2015)	Deep surgical-site infection	0/38	-	1/44	NA
Tsukada (2010)	Deep infection	0/44	-	0/39	NA
Biber (2012)	Infection (%)	-	3.2 (SD ±2.4)	2.5 (SD ±1.4)	0.57
	-	-	**7/217**	**12/487**	
Leonardsson (2016)	Infection as a reason for re-operation	-	12/1140 (1.1%)	13/978 (1.3%)	0.56
Mukka (2016)	Postoperative deep infection rate	-	5/102	5/83	NA
Ozan (2016)	Postoperative infections	-	3/86 (3.4%)	11/147 (7.4%)	0.737
Parker (2015)	Superficial wound infection	-	3/108	2/108	1.0
	Deep wound infection	-	0/108	2/108	0.5
	Cumulative superficial and deep wound infections	-	**3/108**	**4/108**	
Rogmark (2014)	Infections as a risk factor for reoperation (HR)	-	1.0	0.8 (0.7-1.0)	*0.05*
Svenoy (2017)	Surgical site infection	-	20/397 (5%)	12/186 (6%)	0.49

Italic font indicates statistical significance (p < .05). Numbers derived and calculated from article data are indicated in bold. AA, anterior approach; LA, lateral approach; PA, posterior approach; SD, standard deviation; ns, not significant; NA, not available.

Appendix table B.5 Dislocations.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Renken (2012)	Dislocation	0/30	0/27	-	NA
Carlson (2017)	Dislocation	2/82	0/85	-	NA
Baba (2013)	Dislocation rate	0/40	-	1/39	NA
Bush (2007)	Dislocation instability events	0/198	-	9/199 (4.5%)	*0.0033*
Langlois (2015)	Dislocation rate	1/38	-	9/44	*0.02*
Pala (2016)	Dislocation rate	1/55 (1.8%)	-	4/54 (7.4%)	NA
Tsukada (2010)	Dislocations	0/44	-	1/39	0.28
Abram (2015)	Dislocations	-	16/753	7/54	*<0.001*
Biber (2012)	Arthroplasty dislocation, either occurring during inpatient treatment or causing readmission	-	0.5% (SD ±0.9) **1/217**	3.9% (SD ±1.7) **19/487**	*0.01*
Enocnson (2008)	Dislocation rate	-	13/152 (3%)	**32/305 (10.5%)**	*<0.001*
Leonardsson (2016)	Open reduction of a dislocated	-	10/1140 (0.9%)	20/978 (2%)	*0.02*
Mukka (2016)	Single prosthetic dislocation	-	2/102	1/83	NA
	Recurrent prosthetic dislocation	-	1/102	6/83	NA
	Cumulative single and recurrent prosthetic dislocations	-	**3/102**	**7/83**	
Parker (2015)	Dislocation rate	-	2/108 (1.9%)	1/108 (0.9%)	1.0
Rogmark (2014)	Dislocations as a risk factor for reoperation (HR)	-	1.0	2.2 (1.8-2.6)	*0.001*
Ozan (2016)	Postoperative dislocations	-	4/86 (4.6%)	17/147 (11.5%)	0.409
Sayed-Noor (2016)	Dislocations	-	1/24	0/24	NA
Svenoy (2017)	Prosthetic dislocations Recurrent dislocations	- -	4/397 (1%) 2/397 (0.5%)	15/186 (8%) 9/186 (5%)	*<0.001* *0.001*
Sierra (2006)	Dislocations	22/1432	5/125	5/245	NA
Trinh (2015)	Dislocations	0/31	**2/41**	1/29	NA

Italic font indicates statistical significance (p < .05). Numbers derived and calculated from article data are indicated in bold. AA, anterior approach; LA, lateral approach; PA, posterior approach; SD, standard deviation; ns, not significant; NA, not available.

Appendix table B.6 Reoperation rate.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Auffarth (2011)	Revision surgery	1/24	1/24	-	

Appendix table B.6 Reoperation rate. (continued)

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Carlson (2017)	Reoperations	4/85 (4.7%)	5/75 (6.7%)	-	0.57
Langlois (2015)	Revision surgery after dislocations	1/38	-	1/44	NA
Leonardsson (2016)	All open reoperations during study period	-	36/1140 (3%)	40/978 (4%)	0.25
Mukka (2016)	Number of hips with any reoperation	-	9/102 (8.8%)	15/83 (18.1%)	NA
	Adjusted OR for reoperations	-	0.42 (CI 0.16-1.11)	1.0	0.08
Parker (2015)	Reoperations (revision arthroplasty, girdlestone and fixation fracture)	-	**3/108**	**4/108**	NA
Rogmark (2014)	Reoperation rates	-	687/21206 (3.2%)	477/11999 (4.0%)	NA
	Surgical approach as a risk factor for reoperation (HR)	-	1.0	1.4 (CI 1.2-1.8)	*0.001*
Kristensen (2017)	Risk of reoperation (RR)	-	1.0	1.2 (CI 0.91-1.1)	0.2

Italic font indicates statistical significance (p < .05). Numbers derived and calculated from article data are indicated in bold. AA, anterior approach; LA, lateral approach; PA, posterior approach; SD, standard deviation; ns, not significant; NA, not available.

Appendix table B.7 Hospital length of stay.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Carlson (2017)	Mean length of stay (days)	6.2 (SD ±3.1)	8.9 (SD ±7.0)	-	*<0.01*
Baba (2013)	Mean hospitalization period (days)	29.9 (14-50; SD ±**4**)	-	29.3 (17-58; SD ±**10.25**)	NA
Bush (2007)	Average length of stay (days)	7.28 (SD ±3.98)	-	6.41 (SD ±3.52)	*0.0215*
Langlois (2015)	Length of stay (days)	10 (SD ±3,3)	-	8.7 (SD ±4.0)	0.4
Pala (2016)	Time of hospitalization (days)	12 (7-32; SD ±**6.25**)	-	14 (5-32; SD ±**6,75**)	*0,09*
Tsukada (2010)	Length of hospitalization (days)	35.4 (SD ±17,4)	-	36.1 (SD ±21,0)	0,39
Parker (2015)	Mean hospital stay (days)	-	20,3	18,5	0,4

Italic font indicates statistical significance (p < .05). Numbers derived and calculated from article data are indicated in bold. AA, anterior approach; LA, lateral approach; PA, posterior approach; SD, standard deviation; ns, not significant; NA, not available.

Appendix table B.8 Pain.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Auffarth (2011)	Postoperative pain as rated by a VAS (0-10)			-	
	12h	5.6	5.5		
	24h	4.9	4.5		
	48h	4.0	3.1		
	72h	3.3	2.7		
	96h	2.9	2.0		*0.024*
Renken (2012)	Pain VAS			-	
	Day 1 postop (range)	4 (1-8) SD±1.96	5 (2-8) SD±1.66		0.88
	Day 5 postop (range)	2 (0-5) SD±1.4	4 (0-5) SD±1.6		0.14
	Day 16 postop (range)	1 (0-5) SD±1.33	2 (0-4) SD±1.53		0.035
	Day 40 postop (range)	0 (0-1) SD±0.31	1 (0-2) SD±0.82		*0.0004*
Langlois (2015)	Mean pain VAS (0-10) on fifth postoperative day	2.5 (SD ±1.4)	-	2.8 (SD ±1,3)	0.7
	Mean use of any analgesic medication related to hip pain (days)	19	-	22	1.0
	Global pain at latest follow-up (n)	8/38	-	13/44	0.5
Pala (2016)	Postoperative pain (mean NRS score 0-10 of first and second postoperative day)	2.1	-	1.5	*0.0011*
Mukka (2016)	Pain NRS (0-10) at one-year follow-up	-	2.1 (SD ±2.2)	2.0 (SD ±1.7)	ns
Leonardsson (2016)	Patients estimated the average pain in the fracture affected hip over the previous month (VAS)	-	19	17	*0.02*
Kristensen (2017)	Mean pain VAS (0-100) from the operated hip				
	At 4 months	-	22, adj 25	20, adj 23	*0.01*
	At 12 months	-	20, adj 21	17, adj 18	*0.001*
	At 36 months	-	20, adj 20	16, adj 17	*0.02*
Sayed-Noor (2016)	Trochanteric tenderness/pressure pain threshold (using an electronic algometer)	-	89 (SD ±23)	93 (SD ±20)	0.21
	Adjusted OR for trochanteric tenderness/pressure pain threshold	-	-5.58 (-18.9 to 7.76)	1.0	0.40

Italic font indicates statistical significance ($p < .05$). AA, anterior approach; LA, lateral approach; PA, posterior approach; VAS, Visual Analogue Scale; NRS, Numeric Rating Scale; postop, postoperative; ns, not significant; adj, adjusted mean value; OR, odds ratio.

Appendix table B.9 Functionality.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Auffarth (2011)	HHS on postoperative day 10	43.6	46.0	-	NA
	HHS 6 months after the procedure	66.1	67.9	-	NA
	Trendelenburg (n)	2 (8.3%)	3 (12.5%)	-	0.4
Renken (2012)	Modified Barthel score			-	
	Day 1 postop (range)	0 (0-20) SD ±5.8	0 (0-15) SD ±5.4		0.47
	Day 5 postop (range)	20 (0-50) SD ±13.6	10 (0-5) SD ±10.2		*0.009*
	Day 16 postop (range)	25 (5-50) SD ±13.1	20 (0-45) SD ±13.9		*0.05*
	Day 40 postop (range)	42.5 (5-50) SD ±14.6	30 (5-45) SD ±11.9		*0.013*
Carlson (2017)	Feet ambulated on postop day 2	29.0	24.7	-	0.84
	Ambulatory decline at 4-6 weeks	25/52 (48,1%)	20/35 (57,1%)	-	0.41
	Ambulatory decline at 4-6 months	15/50 (26,0%)	12/34 (35,3%)	-	0.70
Baba (2013)	Unaided walking at 2 weeks	26/40	-	13/39	*<0.05*
	Unaided walking at 6 months	27/40		26/39	ns
Tsukada (2010)	Walking ability of the HSS (0-10)				
	1 month after surgery	5.3	-	4.2	
	1 year after surgery	6.3		5.2	NA
	HSS 1 month postoperative	24.2 (SD ±6.4)	-	20.2 (SD ±7.4)	*0.019*
	HSS 1 year postoperative	29.9 (SD ±7.4)	-	27.2 (SD ±7.2)	0.10
Langlois (2015)	Independent walking	50%	-	37%	0.4
	Walking ability at discharge	33/38	-	41/44	1.0
	Use of 2 crutches or walker at discharge	28/38	-w	25/44	0.5
	TUG-test <10	0/38	-	6/44	
	TUG-test 10-19	19/38	-	10/44	
	TUG-test 20-29	7/38	-	16/44	
	TUG-test >30	12/38	-	12/44	0.06
	Outcomes at latest follow-up				
	Walking ability	30/38	-	37/44	1.0
	Use of cane/walker	19/38	-	25/44	0.8

Appendix table B.9 Functionality. (continued)

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Mukka (2016)	HHS at one-year follow-up	-	71 (SD ±18)	72 (SD ±17)	ns
	WOMAC at one-year follow-up	-	79 (SD ±22)	79 (SD ±24)	ns
	Adjusted OR HHS	-	-1.67 (CI -7.87 to 4.54)	1.0	ns
	Adjusted OR WOMAC	-	-1.25 (CI -9.02 to 6.53)	1.0	ns
Sayed-Noor (2016)	Limp twelve months postoperatively	-	12/24	2/24	*0.004*
	HHS twelve months postoperatively	-	75 (SD ±18)	79 (SD ±15)	0.45
	Trendelenburg twelve months postoperatively	-	9/24	1/24	*0.02*
Kristensen (2017)	Walking problems of the EQ-5D				
	After 4 months (favours PA)		NA	NA	*<0.001*
	After 1year (favours PA)		NA	NA	*<0.001*
	After 3 years (favours PA)		NA	NA	*0.009*

Italic font indicates statistical significance ($p < .05$). AA, anterior approach; LA, lateral approach; PA, posterior approach; HHS, Harris Hip Score, TUG, Timed Up and Go test; NA, not available; ns, not significant; HSS, Hospital for Special Surgery hip rating system; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; EQ-5D, EuroQol-5D; postop, postoperative; SD, standard deviation; NA, not available; OR, odds ratio.

Appendix table B.10 Quality of life.

Author (year)	Outcome measure	Approach			p-value
		AA	LA	PA	
Sayed-Noor (2016)	1-year EQ-5D	-	0.16	0.09	0.4
Kristensen (2017)	Mean 4-months EQ-5D	-	0.55 adj 0.45	0.57 adj 0.47	0.2
	Mean 12-months EQ-5D	-	0.61 adj 0.55	0.64 adj 0.58	*0.01*
	Mean 36-months EQ-5D	-	0.61 adj 0.56	0.66 adj 0.60	0.08
Leonardsson (2016)	EQ-5D		0.47 (SD ±0.37)	0.52 (SD ±0.37)	*0.009* adj 0.52
	Satisfaction VAS		24 (SD ±24)	22 (SD ±23)	*0.02* adj 0.25

Italic font indicates statistical significance ($p < .05$). AA, anterior approach; LA, lateral approach; PA, posterior approach; adj, adjusted mean; SD, standard deviation; VAS, Visual Analogue Scale; NA, not available.

Appendix C

Methodological quality assessments

Appendix table C. 1 Methodological quality assessment the randomized studies

	Approaches	RoB 2.0, source of bias				
Author (year)		Randomisation process	Deviations from intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result
Auffarth (2011)	AA – LA	+	+	-	+/-	+/-
Parker (2015)	LA – PA	+	+	-	+/-	+/-
Renken (2012)	AA – LA	+	+	+	+/-	+/-

+ low risk of bias, +/- some concerns of bias, - high risk of bias

Appendix table C. 2 Methodological quality assessment of the comparative cohort studies.

Author (year)	Approaches	ROBINS-I, source of bias						
		confounding	selection of participants	classification of interventions	deviations from intended intervention	missing data	measurement of outcomes	selection of the reported result
Prospective Cohort Studies								
Baba (2013)	AA – PA	-	+	+	+	-	+/-	+/-
Enocson (2008)	LA – PA	+	+	+	+	+	+	+/-
Langlois (2015)	AA – PA	+/-	+/-	+	+	+/-	+/-	+
Mukka (2016)	LA – PA	+	+/-	+	+	+/-	+	+
Sayed-Noor (2016)	LA – PA	+	+	+	+	+	+/-	+
Svenoy (2017)		+	+/-	+	+	+	+	+/-
Tsukada (2010)	AA – PA	+	+	+	+	+/-	+	+
Retrospective Cohort Studies								
Abram (2015)	LA – PA	+/-	+	+	+	+	+	+
Biber (2012)	AA – PA	+/-	+	+	-	-	+/-	-
Bush (2007)	AA – PA	+/-	+	+	+	-	+	-
Carlson (2017)	AA – LA	+/-	+	+	+	+	+	+/-
Kristensen (2017)	LA – PA	+/-	+/-	+	+	+	+	-
Leonardsson (2016)	LA – PA	+/-	-	+	+	+	+	+
Ozan (2016)	LA – PA	+/-	+/-	+	+	+	+	+
Rogmark (2014)	LA – PA	+/-	+	+	+	+/-	+	+/-
Pala (2016)	AA – PA	+/-	-	+	+	+/-	+/-	+
Sierra (2006)	AA – LA – PA	+/-	-	+	+	+	+	+
Trinh (2015)	AA – LA – PA	+/-	+	+	+	+	+/-	+

+ low risk of bias, +/- moderate risk of bias, - serious risk of bias, -- critical risk of bias, N no information

Corrigendum

The authors regret that in Table 1, it is stated that Kristensen et al. (2017) included 18,918 posterior-approach patients and 1990 lateral approach patients.[8] However, in the original article by Kristensen et al. (2017) it is stated that 'The direct lateral approach group had 18,918 patients and the posterior approach group had 1990' (and also presented as such in Table 1 of that original article).[8] The same applies for Figure 2b. This is the only meta-analysis of our systematic review which included results by Kristensen et al. (2017).[8] The mean operation times for each approach (which is analyzed in this meta-analysis), however, are not switched around. This means that the effect-size and the direction of the effect analyzed here is correct. Additionally, the effect weight is also correct as the total amount of patients remains identical. This means that the outcome of this meta-analysis (Fig. 2b) is correct.

In all other places where Kristensen et al. (2017) is referenced (chapters 'Functionality' and 'Quality of Life' of the results, and in the Discussion), the direction of the effect is also handled correctly. The amount of patients included for each approach is not mentioned elsewhere, and of no importance in those sections of our systematic review.

Consequently, the authors conclude that the switched amount of patients per approach group in Table 1 and Figure 2b have no effect on the analyses and the conclusions of their paper. The authors would like to apologise for any inconvenience caused.

The corrections of this corrigendum have already been implemented in this thesis chapter.

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