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ORIGINAL ARTICLE • HIP - ARTHROPLASTY

Comparative outcomes between collared versus collarless and short versus long stem of direct anterior approach total hip arthroplasty: a systematic review and indirect meta-analysis

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Abstract

Introduction Early research shows several advantages of the direct anterior approach (DAA) in THA that claimed to be as effective but less invasive than the posterior approach. However, due to the difficult femoral exposure and possible complications related to femoral preparation, this approach may result in a higher rate of undersized stems when compared to other approaches. The present authors believe that the femoral implant design (collar or collarless stem, short or long stem) in a collared femoral stem may relate to lower rates of stem subsidence and limb length discrepancy (LLD) in mid-term to long-term follow-up when compared to collarless femoral stems. However, currently, there is no consensus as to which femoral implant design is the most suitable for DAA in THA.

Methods This systematic review and meta-analysis aim to assess and compare postoperative complications (neurapraxia, wound infection, LFCN, hematoma, artery injury, cup malposition, embolism, fracture and implant loosening) and revision rates due to dislocation, periprosthetic fracture and implant migration after DAA using collared compared to collarless femoral stem and short femoral stem compared to long femoral stem in THA. These clinical outcomes consist of the postoperative complications and revision femoral stem due to neurapraxia, wound, LFCN and LLD. This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.

Results Relevant studies that reported postoperative complications and revision of either implant were identified from Medline and Scopus from inception to June 6, 2018. Thirty-four studies were included for the analysis of DAA in THA; 23 studies were retrospective cohorts, four studies were prospective cohorts, and seven studies were RCTs. Thirty-one studies and three studies were included for analysis of collarless and collared femoral stems. Twenty-six studies were long femoral stems and eight studies were short femoral stems. Overall, there were 6825 patients (6457 in the collarless group and 368 in the collared group, 4280 in long stem and 2545 in short stem). A total of 469 and 66 patients had complications and revisions in the collarless group, and no patient had complications and revisions in the collared stem group. The total complication and revision rate per patient were 5% (95%CI 3.3%, 7%) and 0.9% (95%CI 0.6%, 1.2%) in all patients. The complication rate and revision rate were 5.7% (95%CI 3.8%, 7.7%) and 0.9% (95%CI 0.6, 1.2) in the collarless group. There was no prevalence of complications and revisions in the collared stem group. The complication rate and revision rate were 10.2% (95%CI 9%, 11.4%), 0.7% (95%CI 0.3%, 1%) and 5.2% (95%CI 3.1, 7.2), 1.5% (95%CI 1%, 2%) in short and long femoral stems, respectively. Indirect meta-analysis shows that collared femoral stem provided a lower risk of complications of 0.02 (95%CI 0.001, 0.30) when compared to collarless femoral stem. Long femoral stems had a lower risk of having complications of 0.57 (95%CI 0.48, 0.68) when compared to short femoral stems. In terms of revision, there is no statistically significant difference in collared femoral stem compared to collarless femoral stem and long femoral stem compared to short femoral stem.

Conclusion In DAA THA, collared femoral stem and long femoral stem had decreased complication rates when compared to collarless femoral stem and short femoral stem by both direct and indirect meta-analysis methods. However, in terms

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of revision rates, there were no differences between all femoral stems (short versus long and collared versus collarless). Prospective randomized controlled studies are needed to confirm these findings as the current literature is still insufficient.

Keywords Systematic review · Meta-analysis · THA · Collar femoral stem · Short femoral stem

Abbreviations

THA	Total hip arthroplasty
DAA	Direct Anterior Approach
PA	Posterior approach
LLD	Limb length discrepancy
RCT	Randomized controlled trial
SD	Standard deviation
BMI	Body mass index
LFCN	Lateral Femoral Cutaneous Nerve
OR	Odds ratio
OA	Osteoarthritis

Introduction

Surgical approaches in total hip arthroplasty (THA) include anterior [17, 26, 33, 40, 43, 48, 50, 58, 60], lateral [1, 13, 27, 61, 63] and direct lateral and posterior approach [2, 7, 8, 18, 54, 64]. Early research [42] shows several advantages of the direct anterior approach (DAA) in THA that claims to be as effective but less invasive than the posterior approach (PA). However, the higher risk of femoral fracture and soft tissue damage cannot be underestimated. Due to the difficult femoral exposure and possible complications related to femoral preparation, this approach can result in a higher rate of undersized stems when compared to other approaches [6, 10, 22, 29, 34, 47]. The present authors believe that the femoral implant design (collar [3–5] or collarless stem [6, 10, 22, 29, 34, 47], long [3–6, 10, 22, 29, 34, 47] or short stem [8, 15, 20, 30, 38, 39, 41, 49]) in the collared femoral stem may relate to a lower rate of stem subsidence and limb length discrepancy (LLD) in mid-term to long-term follow-up when compared to collarless femoral stem. However, currently there is no consensus as to which femoral implant design is the most suitable for DAA in THA. Therefore, this systematic review and meta-analysis aim to assess and compare postoperative complications and revision rates due to neurapraxia, wound complications, LFCN and LLD after DAA using collared compared to collarless femoral stem and short femoral stem compared to long femoral stem in THA. These clinical outcomes consist of the postoperative complications (neurapraxia, wound infection, LFCN, hematoma, artery injury, cup malposition, embolism, fracture and implant loosening) and revision rates due to dislocation, periprosthetic fracture and implant migration.

Material and method

Medline and Scopus databases were used to identify relevant studies published in English since the date of inception to June 6, 2018. The PubMed and Scopus search engines were used to locate studies with the following search terms: [(DAA OR direct anterior approach) AND total hip arthroplasty]. Search strategies for Medline and Scopus are described in detail in "Appendix1". References from the reference lists of included trials and previous systematic reviews were also explored.

Inclusion criteria

Clinical studies (e.g., observational, cross sectional, cohort or RCT) that reported clinical outcomes of DAA using collar compared to collarless femoral stem and short femoral stem compared to long femoral stem in THA were eligible if they met the following criteria:

- Reported at least one of the following outcomes: complications (neurapraxia, wound infection, LFCN, hematoma, artery injury, cup malposition, embolism, fracture and implant loosening) and revision rates due to dislocation, periprosthetic fracture and implant migration.
- Had sufficient data to extract and pool, i.e., the reported mean, standard deviation (SD), the number of subjects according to treatments for continuous outcomes, and the number of patients according to treatment for dichotomous outcomes.

The reference lists of the retrieved articles were also reviewed to identify publications on the same topic. Where there were multiple publications from the same study group on the same population, the most complete and recent results were used. Non-English studies were excluded.

Data extraction

Two reviewers (P.P. and J.K.) independently performed data extraction using standardized data extraction forms. General characteristics of the study [i.e., mean age, gender, body mass index (BMI), mean follow-up time, study design, type of approach (MIS or standard), implant design (short or long stem, collar or collarless) and fixation method (cemented or cementless)] were extracted. All dichotomous outcomes (postoperative complications and revision of femoral stem due to neurapraxia, wound complications, LFCN and LLD) were also extracted. Any disagreements were resolved by discussion and consensus with a third party (A.A.).

Outcomes of interest

The outcomes of interest included postoperative complications and revision of the femoral stem. These outcomes were measured as reported in the original studies which were postoperative complications (neurapraxia, wound infection, LFCN, hematoma, artery injury, cup malposition, embolism, fracture and implant loosening) and revision rates due to dislocation, periprosthetic fracture and implant migration were considered.

Statistical analysis

For dichotomous outcomes (complications and revision), the prevalence was pooled and calculated using the inverse variance method as follows [55]: $\bar{p} = \frac{\sum w_i p_i}{\sum w_i}$ where p was the pooled prevalence, p_i was the prevalence of complications of each study, w_i was $1/\mathrm{var}(p_i)$, which was the weight of each study. Heterogeneity of prevalence across studies p was checked as follows: $\sum w_i \left(p_i - \bar{p}\right)^2$ The Q statistic follows a χ^2 distribution with number of studies $(k) - 1$ degree of freedom (d.f.). The degree of heterogeneity was also quantified using the I^2 statistic [23]. This value can range from 0 to 100%, the closer to 100%, the higher the heterogeneity. If heterogeneity was present, between studies variation was then estimated as follows: $\tau^2 = \frac{Q-(k-1)}{\sum w_i - \frac{\sum w_1^2}{\sum w_1}}$ if Q k 1 or 0 otherwise. This was used to calculate a weight term that accounted for variations between studies $w_i^* = \frac{1}{\mathrm{var}(p_1) = \tau^2}$, and then the pooled prevalence was estimated using the random effects model as follows: $95\%\mathrm{CI} = \bar{p}^* \pm \frac{1.96}{\sqrt{\sum w_i^*}}$. Meta-regression analysis was then applied to explore causes of heterogeneity [23, 56]. Coverable parameters, i.e., mean age, gender, body mass index (BMI), mean follow-up time, study design, type of approach (MIS or standard), implant design (short or long stem, collar or collarless) and fixation method (cemented or cementless) were considered in the meta-regression model. Power of the test for meta-regression was also assessed [51]. The unstandardized mean difference and odds ratio (OR) were estimated by indirect meta-analysis using a random effects model, otherwise a fixed effects model was applied. All analyses were performed using STATA version 14.0 [57].

Results

Three hundred and twenty-seven and 338 studies were identified from Medline and Scopus, respectively, as shown in Fig. 1. Two hundred and sixteen studies were duplicates, leaving 449 studies for review of titles and abstracts. Of

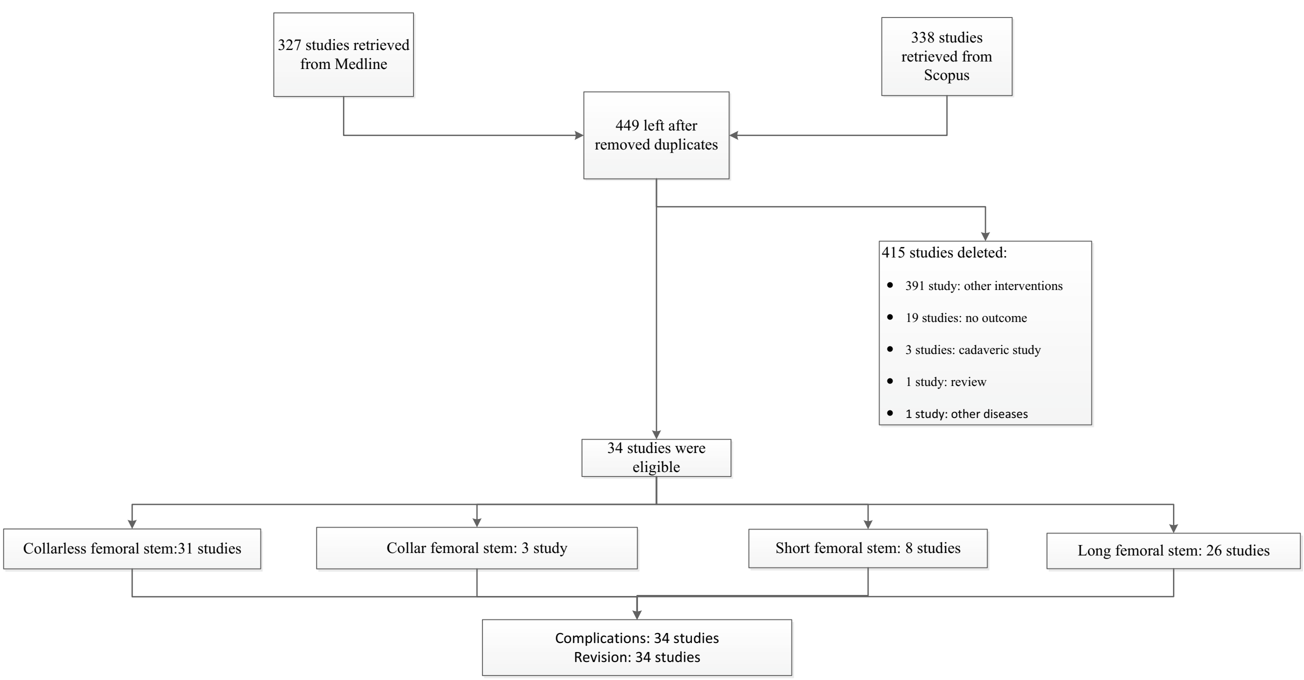

Fig. 1 Flow of study select

Table 1 Characteristics of included studies of DAA in long stem

Study	Year	Design	MIS	Disease	*N*	Women	BMI	Age	F/U (month)	Stem type	Implant	Cement fixation	Complications	Revision
Kanda A	2018	RC	No	Primary OA and ON	103	0.87	–	65.6	6 month	Long	Collarless	Cementless	0	0
Sariali E	2017	PC	Yes	Primary OA and ON	154	0.37	26.5	58.8	5 year	Long	Collarless	Both	2	0
Nakmura J	2017	PC	No	OA ON and RA	100	0.82	23.6	62.3	2 year	Long	Collarless	Both	5	1
Kawarai Y	2017	RC	No	OA ON and RA	106	0.9	23.7	67.3	1 year	Long	Collarless	Cemented	5	0
Hartford JM	2017	RC	No	OA ON and RA	442	0.72	28.4	66	2 year	Long	Collarless	Both	18	9
Guild GN	2017	RC	No	–	232	0.51	29.6	60.6	1.5 month	Long	Collarless	Cementless	0	0
Cohen EM	2017	RC	No	–	487	0.55	–	66.55	1 year	Long	Collarless	Cementless	12	0
Chen M	2017	PC	No	OA ON and RA	96	0.55	26.8	58.1	1 year	Long	Collarless	Cementless	56	1
Tamaki T	2016	RC	No	hip dysplasia	790	0.93	–	62.4	7.8 year	Long	Collarless	Cementless	15	8
Homma Y	2016	RC	No	–	120	–	–	–	1.89 year	Long	Collarless	Cementless	0	0
Fransen B	2016	RC	No	–	45	0.67	25	64.2	1 year	Long	Collarless	Cementless	8	0
Hamilton WG	2015	RC	No	primary OA	100	0.64	28.8	62.5	2.5 year	Long	Collarless	Cementless	4	2
Zawadsky MW	2014	RC	Yes	OA and ON	100	0.54	28.2	60.2	1.5 month	Long	Collarless	Cementless	11	2
Taunton MJ	2014	RCT	Yes	primary OA	27	0.52	27.7	66.4	1 year	Long	Collarless	Cementless	2	0
Rodriguez JA	2014	PC	No	primary OA	60	0.53	27	60	1 year	Long	Collarless	Cementless	4	0
Hoell S	2014	RC	Yes	OA ON and RA	107	0.49	–	59.6	2 year	Long	Collarless	Both	7	1
De Geest T	2013	RC	Yes	–	300	0.45	–	69.8	1 year	Long	Collarless	Both	51	20
William B	2014	RC	No	Primary OA	43	0.33	30.7	61.4	1 year	Long	Collarless	Cementless	10	0
Kleinert K	2012	RCT	No	OA	120	0.51	27	65	3 month	Long	Collarless	Cementless	16	4
Restrepo C	2010	RCT	No	OA	50	0.66	25.18	62.02	2 year	Long	Collarless	Cementless	0	0
Nakata K	2009	RC	Yes	OA ON and RA	99	0.84	22.9	62.9	1 year	Long	Collarless	Cementless	0	0
Oinuma K	2007	RC	No	–	111	0.74	23.1	62.5	1.5 year	Long	Collarless	Cementless	4	0
Zhao HY	2017	RCT	No	Primary OA	120	0.58	24.5	63.8	6 month	Long	Collarless	Cementless	0	0
Bingham JS	2018	RC	No	Primary OA	298	0.47	28.2	65.9	1.5 month	Long	Collar	Cementless	0	0
Bernard J	2018	RC	Yes	Primary OA	11	–	26.46	64.55	–	Long	Collar	Cementless	0	0
Brown ML	2017	RC	No	Primary OA and ON	59	0.46	27.2	58.5	3 month	Long	Collar	Cementless	0	0

Table 2 Characteristics of included studies of DAA in short stem

Study	Year	Design	MIS	Disease	*N*	Women	BMI	Age	F/U (month)	Stem type	Implant	Cement fixation	Complications	Revision
Fahs AM	2018	RCT	No	Primary OA	100	0.48	27.4	66.5	0.75 m	Short	Collarless	Cementless	0	0
Ponzio DY	2018	RC	No	–	289	0.58	28.4	65.1	4 y	Short	Collarless	Cementless	21	2
Perry CR	2018	RCT	No	Primary OA	50	0.54	–	58.4	0.75 m	Short	Collarless	Cementless	0	0
Patton RS	2018	RC	No	Primary OA	1665	0.6	–	61.1	8 year	Short	Collarless	Both	183	10
Khemka A	2018	RC	No	Primary OA and ON	138	0.39	29	62	3.5 year	Short	Collarless	Cementless	18	0
Shemesh SS	2017	RC	No	Primary OA and ON	75	0.59	26.6	62.4	1.5 month	Short	Collarless	Cementless	0	0
Hallert O	2012	RC	Yes	OA	200	0.61	26.7	67.4	1 year	Short	Collarless	Cementless	17	6
Christensen CP	2015	RCT	No	Primary OA	28	0.54	31.1	64.3	1.5 month	Short	Collarless	Cementless	0	0

these, 34 articles [3–6, 8, 10, 11, 15, 16, 19–22, 24, 25, 28–31, 34–36, 38, 39, 41, 44, 46, 47, 49, 53, 54, 62, 65, 66] were relevant, and the full papers were retrieved. Characteristics of these studies are given in Tables 1 and 2. Thirty-four studies [3–6, 8, 10, 11, 15, 16, 19–22, 24, 25, 28–31, 34–36, 38, 39, 41, 44, 46, 47, 49, 53, 54, 62, 65, 66] were included for the analysis of DAA in THA; 23 studies [3–5, 10, 11, 16, 19–22, 24, 25, 28–30, 35, 36, 38, 41, 49, 53, 62, 65] were retrospective cohort, four studies [6, 34, 46, 47] were prospective cohort, and seven studies [8, 15, 31, 39, 44, 54, 66] were RCTs. Thirty-one studies [6, 8, 10, 11, 15, 16, 19–22, 24, 25, 28–31, 34–36, 38, 39, 41, 44, 46, 47, 49, 53, 54, 62, 65, 66] and three studies [3–5] were included for analysis of collarless and collared femoral stem. Twenty-six studies [3–6, 10, 11, 15, 16, 19, 21, 22, 24, 25, 28, 29, 31, 34–36, 44, 46, 47, 53, 54, 62, 65, 66] were long femoral stem, and eight studies [8, 20, 30, 38, 39, 41, 49] were short femoral stem. Twenty-seven studies [3–6, 8, 10, 15, 16, 19–21, 25, 28, 30, 31, 35, 36, 39, 41, 44, 46, 49, 53, 54, 62, 65, 66] were cementless fixation, seven studies [11, 22, 24, 34, 38, 47] were fixation with both cemented and cementless, and one study [29] was cemented fixation. Twenty-six studies [4–6, 8, 10, 15, 16, 19, 21, 22, 25, 28–31, 34, 36, 38, 39, 41, 44, 46, 49, 53, 62, 66] were standard approach, and eight studies [3, 11, 20, 24, 35, 47, 54, 65] were minimally invasive surgery approach. Twelve studies were primary osteoarthritis (OA), seven studies were primary OA and osteonecrosis, one study was hip dysplasia, and seven studies did not mention the cause of pathology. Mean age, BMI, mean follow-up and percentages of female gender of long-stem DAA participants varied from 58.1 to 69.8 years, 22.9 to 30.7 kg/m^2, 1 to 94 months and 32.6 to 92.8%, while short stem varied from 58.4 to 67.4 years, 26.6 to 31.1 kg/m^2, 1.5 to 96 months and 39.1 to 60.5%.

Pooled prevalence of complications and revision between collar and collarless DAA

Overall, there were 6825 patients (6457 in the collarless group and 368 in the collar group). A total of 469 and 66 patients had complications and revision in the collarless group and no patient had complications and revision in the collar stem group (Supplement Table 1). The total complication and revision rate per patient was 5% (95%CI 3.3%, 7%) and 0.9% (95%CI 0.6%, 1.2%) in the all patients. The complication rate and revision rate were 5.7% (95%CI 3.8%, 7.7%) and 0.9% (95%CI 0.6, 1.2) in the collarless group. There was no prevalence of complication and revision in the collared stem group. By indirect meta-analysis, collared femoral stem provided a lower risk of having complications of 0.02 (95%CI 0.001, 0.30) when compared to collarless femoral stem. In terms of revision, there was no statistically

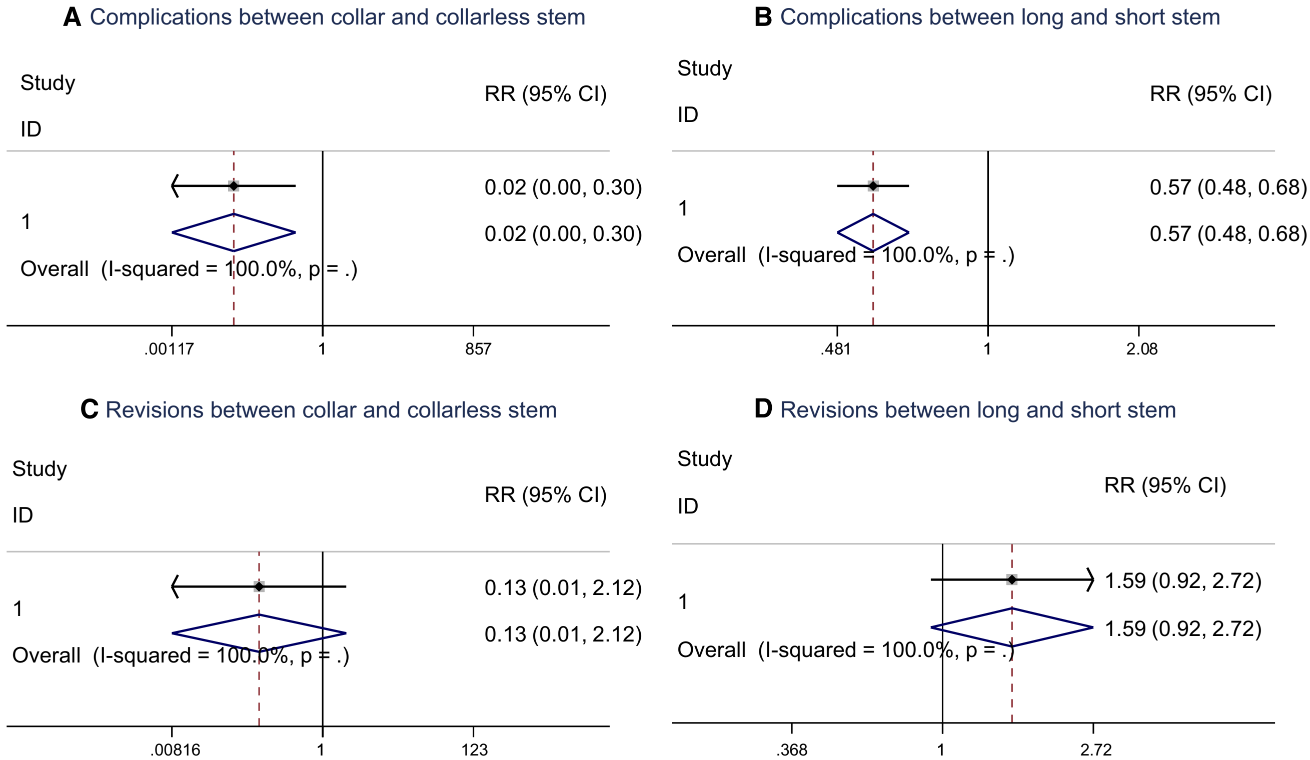

Fig. 2 Comparisons of prevalence of complications and revisions between short versus long stem or collar versus collarless stem

significant difference in collared femoral stem compared to collarless femoral stem (Fig. 2, Table 3).

Pooled prevalence of complications and revision between short- and long-stem DAA

Four thousand two hundred and eighty patients in long stem and 2545 patients in short stem were selected. The complication rate and revision rate were 10.2% (95%CI 9%, 11.4%), 0.7% (95%CI 0.3%, 1%) and 5.2% (95%CI 3.1, 7.2), 1.5% (95%CI 1%, 2%) in short and long femoral stem, respectively (Supplement Table 1). By indirect meta-analysis, the long femoral stem had a lower risk of having complications 0.57 (95%CI 0.48, 0.68) when compared to short femoral stem. In terms of revision, there was no statistically significant difference in long femoral stem compared to short femoral stem (Table 4).

Sources of heterogeneity

Meta-regression was applied for exploring the cause of heterogeneity by fitting a co-variable (i.e., age, percentage of female patients, BMI, follow-up time and type of disease and study quality), and meta-regression was applied to assess this. None of the co-variables could explain the heterogeneity (Table 5).

Discussion

From the current available evidence, this systematic review and meta-analysis have shown the following: collared femoral stem provides a lower risk of having complications of 0.02 (95%CI 0.001, 0.30) when compared to collarless femoral stem. Long femoral stem had a lower risk of complications by 0.57 (95%CI 0.48, 0.68) when compared to short femoral stem. In terms of revision, there was no statistically significant difference in collared femoral stem compared to collarless femoral stem and long femoral stem compared to short femoral stem.

The issue of increased risk of revision for femoral-related complications with the anterior approach has been debated in the literature recently. Many studies [9, 14, 32, 37, 45, 59] reported that increased rate of revision for early femoral failure secondary to loosening or fracture in patients who had undergone total hip arthroplasty via the DAA approach compared to the posterior approach. An interesting finding of these studies was the effect of stem design on the rate of femoral loosening or fracture such as short stem [52], undersized stem [45] and collarless tapered stem [9, 52]. The hypothesis on the increased rate of loosening with the tapered wedge inserted via an anterior approach is that there is an increased risk of loosening due to failure to obtain adequate initial stability and subsequent ingrowth. In the

Table 3 Estimation of the pooled prevalence of complications and revisions of collar versus collarless DDA approaches

Author	*N*	Collarless stem			
		Complication		Fusion	
		Yes	No	Yes	No
Fahs AM	100	0	100	0	100
Zhao HY	120	0	120	0	120
Ponzio DY	289	21	268	2	287
Perry CR	50	0	50	0	50
Patton RS	1665	183	1482	10	1655
Khemka A	138	18	120	0	138
Kanda A	103	0	103	0	103
Shemesh SS	75	0	75	0	75
Sariali E	154	2	152	0	154
Nakamura J	100	5	95	1	99
Kawarai Y	106	5	101	0	106
Hartford JM	442	18	424	9	433
Guild GN	232	0	232	0	232
Cohen EM	487	12	475	0	487
Chen M	96	56	40	1	95
Tamaki T	790	15	775	8	782
Homma Y	120	0	120	0	120
Fransen B	45	8	37	0	45
Hamilton WG	100	4	96	2	98
Christensen CP	28	0	28	0	28
Zawadsky MW	100	11	89	2	98
Taunton MJ	27	2	25	0	27
Rodriguez JA	60	4	56	0	60
Hoell S	107	7	100	1	106
De Geest T	300	51	249	20	280
William B	43	10	33	0	43
Kleinert K	120	16	104	4	116
Hallert O	200	17	183	6	194
Restrepo C	50	0	50	0	50
Nakata K	99	0	99	0	99
Oinuma K	111	4	107	0	111
Pooled mean (95%CI)	5457	0.057 (0.038, 0.077)		0.009% (0.006, 0.012)	
Author	*N*	Collar stem			
		Complications		Revisions	
		Yes	No	Yes	No
Bingham JS	298	0	298	0	298
Bernard J	11	0	11	0	11
Brown ML	59	0	59	0	59
Pooled mean (95%CI)	368	0		0	

anterior approach, broaching trajectory is not always linear; this may be secondary to patient body habitus, femoral exposure, or the patient's proximal femoral anatomy. With a thin, collarless tapered stem design, nonlinear broach insertion and extraction can create an anterior metaphyseal gap that compromises initial stability leading to subsidence, distal potting and failure of proximal ingrowth [9]. Our study found that the collared stem lowered the risk of loosening or fracture when compared to the collarless stem, which is a similar result to some large retrospective studies [9]. A

Table 4 Estimation of the pooled prevalence of complications and revisions of short- versus long-stem DDA approaches

Author	*N*	Long stem			
		Complications		Revisions	
		Yes	No	Yes	No
Kanda A	103	0	103	0	103
Sariali E	154	2	152	0	154
Nakamura J	100	5	95	1	99
Kawarai Y	106	5	101	0	106
Hartford JM	442	18	424	9	433
Guild GN	232	0	232	0	232
Cohen EM	487	12	475	0	487
Chen M	96	56	40	1	95
Tamaki T	790	15	775	8	782
Homma Y	120	0	120	0	120
Fransen B	45	8	37	0	45
Hamilton WG	100	4	96	2	98
Zawadsky MW	100	11	89	2	98
Taunton MJ	27	2	25	0	27
Rodriguez JA	60	4	56	0	60
Hoell S	107	7	100	1	106
De Geest T	300	51	249	20	280
William B	43	10	33	0	43
Kleinert K	120	16	104	4	116
Restrepo C	50	0	50	0	50
Nakata K	99	0	99	0	99
Oinuma K	111	4	107	0	111
Zhao HY	120	0	120	0	120
Bingham JS	298	0	298	0	298
Bernard J	11	0	11	0	11
Brown ML	59	0	59	0	59
Pooled mean (95%CI)	4280	0.052 (0.031, 0.072)		0.015 (0.010, 0.020)	
Author	*N*	Short stem			
		Complications		Revisions	
		Yes	No	Yes	No
Fahs AM	100	0	100	0	100
Ponzio DY	289	21	268	2	287
Perry CR	50	0	50	0	50
Patton RS	1665	183	1482	10	1655
Khemka A	138	18	120	0	138
Shemesh SS	75	0	75	0	75
Hallert O	200	17	183	6	194
Christensen CP	28	0	28	0	28
Pooled mean (95%CI)	2545	0.102 (0.09, 0.114),		0.007 (0.003, 0.010)	

collared stem offers numerous theoretical advantages such as reduced subsidence, better rotational stability, and lower risks of calcar fracture propagation [9]. These theories were confirmed in a cohort study in which Demey et al. [12] found that collared Corail stems were able to withstand greater vertical and horizontal forces before the initiation of subsidence and subsequent fracture. As the femoral stem is at greatest risk of subsidence or early fracture before secondary fixation (osseointegration), it is possible that the improved immediate stability conferred by collared stems allows more

Table 5 Comparisons of prevalence of complications and revisions between short and long stem or collar and collarless stem

Author	Complications				OR	95% CI
	Long		Short			
	Yes	No	Yes	No		
Pooled study	230	4050	239	2306	0.57	0.48, 0.68
Author	Revisions				OR	95% CI
	Long		Short			
	Yes	No	Yes	No		
Pooled study	48	4232	18	2527	1.59	0.93, 2.7
Author	Complications				OR	95% CI
	Collar		Collarless			
	Yes	No	Yes	No		
Pooled study	0	368	469	5988	0.02	0.001, 0.30
Author	Revisions				OR	95% CI
	Collar		Collarless			
	Yes	No	Yes	No		
Pooled study	0	368	66	6391	0.13	0.01, 2.12

rapid bony ingrowth to achieve secondary fixation. This may be of increased importance with the current emphasis on early functional recovery after THA. Moreover, Cidambi et al. [9] reported that the implantation of a collared HA-coated compaction broached stem or metaphyseal fit and fill stem is now routinely used at their center for primary THA via the DAA because of the aforementioned benefits. Therefore, our results confirmed that collared femoral stem should be used as implant of choice to decrease risk of femoral-related complications in DAA for THA.

The strength of this study is that we use adequate methodology of systematic reviews in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [106] as well as providing exploration and reduction in the heterogeneity of the studies using subgroup analysis and adequate statistical analysis.

Moreover, this study has conclusive evidence about long femoral stem and collar femoral stem should be selected to decrease complication and revision after DAA for THA.

There are some limitations in this study. First of all, the quality of studies for the meta-analysis was not high. Ideal evidence for systematic review is a randomized controlled trial (RCT), which is most commonly used in testing the efficacy of surgery. The quality of data available is relatively poor, with a predominance of non-comparative retrospective studies. There were no randomized controlled trials or prospective comparative studies. This could be a possible source of bias between groups due to the opportunity for selection, different baseline characteristics and likely for publication bias. Secondly, heterogeneity remains an important factor to be considered in the conduct and interpretation of meta-analysis, and the heterogeneity between studies was great. We applied the random effects meta-analysis to adjust for the differences between studies, and the possible causes of heterogeneity were explored if covariate data at baseline (e.g., age, percentage of female patients, BMI, follow-up time, type of disease and study quality) were available. The third limitation is that there is also a measurement bias, as the studies differed in their definition and reporting of complications. The fourth limitation is that indirect meta-analysis was used for calculating the mean difference and odds ratio between the two groups, due to the fact that most included studies were case series reports of only one technique. The fifth limitation is that there are other outcomes of interest that can be used to compare collared and collarless stem such as operation cost and quality of life. However, these factors could not be analyzed because of insufficient data. The sixth limitation is that among studies, the follow-up time varied, which could affect reports of reoperation rates. Finally, several studies did not make specific mention of certain complications. In this study, it was assumed that those complications were not present rather than not reported for the primary outcome analysis. This is a potential source of bias.

In conclusion DAA THA, collared femoral stem and long femoral stem had better complication rates when compared to collarless femoral stem and short femoral stem with direct and indirect meta-analysis methods. However, in terms of revision rates, there were no differences between all femoral stems (short versus long and collared versus collarless). Prospective randomized controlled studies are needed to confirm these findings as the current literature is still insufficient.

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Authors' contributions PP was involved in conception and design, analysis and interpretation of the data, drafting of the article, critical revision of the article for important intellectual content, final approval of the article, collection and assembly of data. SB was involved in conception and design, drafting of the article, critical revision of the article for important intellectual content, final approval of the article. AA was involved in conception and design, drafting of the article, critical revision of the article for important intellectual content, final approval of the article, collection and assembly of data. JK was involved in conception and design, analysis and interpretation of the data, drafting of the article, critical revision of the article for important intellectual content, final approval of the article, collection and assembly of data.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflicts of interests.

Ethical standards This article does not contain any studies with human participants performed by any of the authors.

Appendix 1: Search term and search strategy

#1 DAA
#2 direct anterior approach
#3 total hip arthroplasty
#4#1 or #2
#5 #3 and #4.

References

1. Baker AS, Bitounis VC (1989) Abductor function after total hip replacement. An electromyographic and clinical review. J Bone Jt Surg Br 71(1):47–50
2. Barrett WP, Turner SE, Leopold JP (2013) Prospective randomized study of direct anterior vs postero-lateral approach for total hip arthroplasty. J Arthroplasty 28(9):1634–1638. https://doi.org/10.1016/j.arth.2013.01.034
3. Bernard J, Razanabola F, Beldame J, Van Driessche S, Brunel H, Poirier T, Matsoukis J, Billuart F (2018) Electromyographic study of hip muscles involved in total hip arthroplasty: surprising results using the direct anterior minimally invasive approach. Orthop Traumat Surg Res OTSR. https://doi.org/10.1016/j.otsr.2018.03.013
4. Bingham JS, Spangehl MJ, Hines JT, Taunton MJ, Schwartz AJ (2018) Does intraoperative fluoroscopy improve limb-length discrepancy and acetabular component positioning during direct anterior total hip arthroplasty? J Arthroplasty. https://doi.org/10.1016/j.arth.2018.05.004
5. Brown ML, Plate JF, Holst DC, Bracey DN, Bullock MW, Lang JE (2017) A retrospective analysis of the merits and challenges associated with simultaneous bilateral THA using the direct anterior approach. Hip Int J Clin Exp Res Hip Pathol Therapy 27(2):169–174. https://doi.org/10.5301/hipint.5000449
6. Chen M, Luo Z, Ji X, Cheng P, Tang G, Shang X (2017) Direct anterior approach for total hip arthroplasty in the lateral decubitus position: our experiences and early results. J Arthroplasty 32(1):131–138. https://doi.org/10.1016/j.arth.2016.05.066
7. Cheng TE, Wallis JA, Taylor NF, Holden CT, Marks P, Smith CL, Armstrong MS, Singh PJ (2016) A prospective randomized clinical trial in total hip arthroplasty-comparing early results between the direct anterior approach and the posterior approach. J Arthroplasty. https://doi.org/10.1016/j.arth.2016.08.027
8. Christensen CP, Jacobs CA (2015) Comparison of patient function during the first six weeks after direct anterior or posterior total hip arthroplasty (THA): a randomized study. J Arthroplasty 30(9 Suppl):94–97. https://doi.org/10.1016/j.arth.2014.12.038
9. Cidambi KR, Barnett SL, Mallette PR, Patel JJ, Nassif NA, Gorab RS (2018) Impact of femoral stem design on failure after anterior approach total hip arthroplasty. J Arthroplasty 33(3):800–804. https://doi.org/10.1016/j.arth.2017.10.023
10. Cohen EM, Vaughn JJ, Ritterman SA, Eisenson DL, Rubin LE (2017) Intraoperative femur fracture risk during primary direct anterior approach cementless total hip arthroplasty with and without a fracture table. J Arthroplasty 32(9):2847–2851. https://doi.org/10.1016/j.arth.2017.04.020
11. De Geest T, Vansintjan P, De Loore G (2013) Direct anterior total hip arthroplasty: complications and early outcome in a series of 300 cases. Acta Orthop Belg 79(2):166–173
12. Demey G, Fary C, Lustig S, Neyret P, si Selmi T (2011) Does a collar improve the immediate stability of uncemented femoral hip stems in total hip arthroplasty? A bilateral comparative cadaver study. J Arthroplasty 26(8):1549–1555. https://doi.org/10.1016/j.arth.2011.03.030
13. Downing ND, Clark DI, Hutchinson JW, Colclough K, Howard PW (2001) Hip abductor strength following total hip arthroplasty: a prospective comparison of the posterior and lateral approach in 100 patients. Acta Orthop Scand 72(3):215–220. https://doi.org/10.1080/00016470152846501
14. Eto S, Hwang K, Huddleston JI, Amanatullah DF, Maloney WJ, Goodman SB (2017) the direct anterior approach is associated with early revision total hip arthroplasty. J Arthroplasty 32(3):1001–1005. https://doi.org/10.1016/j.arth.2016.09.012
15. Fahs AM, Koueiter DM, Kurdziel MD, Huynh KA, Perry CR, Verner JJ (2018) psoas compartment block vs periarticular local anesthetic infiltration for pain management after anterior total hip arthroplasty: a prospective, randomized study. J Arthroplasty. https://doi.org/10.1016/j.arth.2018.02.052
16. Fransen B, Hoozemans M, Vos S (2016) Direct anterior approach versus posterolateral approach in total hip arthroplasty: one surgeon, two approaches. Acta Orthop Belg 82(2):240–248
17. Goebel S, Steinert AF, Schillinger J, Eulert J, Broscheit J, Rudert M, Noth U (2012) Reduced postoperative pain in total hip arthroplasty after minimal-invasive anterior approach. Int Orthop 36(3):491–498. https://doi.org/10.1007/s00264-011-1280-0
18. Goosen JH, Kollen BJ, Castelein RM, Kuipers BM, Verheyen CC (2011) Minimally invasive versus classic procedures in total hip arthroplasty: a double-blind randomized controlled trial. Clin Orthop Relat Res 469(1):200–208. https://doi.org/10.1007/s11999-010-1331-7

19. Guild GN 3rd, Runner RP, Castilleja GM, Smith MJ, Vu CL (2017) Efficacy of hybrid plasma scalpel in reducing blood loss and transfusions in direct anterior total hip arthroplasty. J Arthroplasty 32(2):458–462. https://doi.org/10.1016/j.arth.2016.07.038
20. Hallert O, Li Y, Brismar H, Lindgren U (2012) The direct anterior approach: initial experience of a minimally invasive technique for total hip arthroplasty. J Orthop Surg Res 7:17. https://doi.org/10.1186/1749-799x-7-17
21. Hamilton WG, Parks NL, Huynh C (2015) Comparison of cup alignment, jump distance, and complications in consecutive series of anterior approach and posterior approach total hip arthroplasty. J Arthroplasty 30(11):1959–1962. https://doi.org/10.1016/j.arth.2015.05.022
22. Hartford JM, Bellino MJ (2017) The learning curve for the direct anterior approach for total hip arthroplasty: a single surgeon's first 500 cases. Eur J Orthop Surg Traumatol Orthop Traumatol 27(5):483–488. https://doi.org/10.5301/hipint.5000488
23. Higgins JP, Thompson SG (2002) Quantifying heterogeneity in a meta-analysis. Stat Med 21(11):1539–1558. https://doi.org/10.1002/sim.1186
24. Hoell S, Sander M, Gosheger G, Ahrens H, Dieckmann R, Hauschild G (2014) The minimal invasive direct anterior approach in combination with large heads in total hip arthroplasty—is dislocation still a major issue? a case control study. BMC Musculoskelet Disord 15:80. https://doi.org/10.1186/1471-2474-15-80
25. Homma Y, Baba T, Kobayashi H, Desroches A, Ozaki Y, Ochi H, Matsumoto M, Yuasa T, Kaneko K (2016) Safety in early experience with a direct anterior approach using fluoroscopic guidance with manual leg control for primary total hip arthroplasty: a consecutive one hundred and twenty case series. Int Orthop 40(12):2487–2494. https://doi.org/10.1007/s00264-016-3159-6
26. Ilchmann T, Gersbach S, Zwicky L, Clauss M (2013) Standard transgluteal versus minimal invasive anterior approach in hip arthroplasty: a prospective, consecutive cohort study. Orthop Rev 5(4):e31. https://doi.org/10.4081/or.2013.e31
27. Ji HM, Kim KC, Lee YK, Ha YC, Koo KH (2012) Dislocation after total hip arthroplasty: a randomized clinical trial of a posterior approach and a modified lateral approach. J Arthroplasty 27(3):378–385. https://doi.org/10.1016/j.arth.2011.06.007
28. Kanda A, Kaneko K, Obayashi O, Mogami A, Morohashi I (2018) Preservation of the articular capsule and short lateral rotator in direct anterior approach to total hip arthroplasty. Eur J Orthop Surg Traumatol Orthop Traumatol. https://doi.org/10.1007/s00590-018-2166-2
29. Kawarai Y, Iida S, Nakamura J, Shinada Y, Suzuki C, Ohtori S (2017) Does the surgical approach influence the implant alignment in total hip arthroplasty? Comparative study between the direct anterior and the anterolateral approaches in the supine position. Int Orthop 41(12):2487–2493. https://doi.org/10.1007/s00264-017-3521-3
30. Khemka A, Mograby O, Lord SJ, Doyle Z, Al Muderis M (2018) Total hip arthroplasty by the direct anterior approach using a neck-preserving stem: safety, efficacy and learning curve. Indian J Orthop 52(2):124–132. https://doi.org/10.4103/ortho.IJOrtho_314_16
31. Kleinert K, Werner C, Mamisch-Saupe N, Kalberer F, Dora C (2012) Closed suction drainage with or without re-transfusion of filtered shed blood does not offer advantages in primary non-cemented total hip replacement using a direct anterior approach. Arch Orthop Trauma Surg 132(1):131–136. https://doi.org/10.1007/s00402-011-1387-1
32. Meneghini RM, Elston AS, Chen AF, Kheir MM, Fehring TK, Springer BD (2017) Direct anterior approach: risk factor for early femoral failure of cementless total hip arthroplasty: a multicenter study. J Bone Jt Surg Am 99(2):99–105. https://doi.org/10.2106/jbjs.16.00060
33. Mirza AJ, Lombardi AV Jr, Morris MJ, Berend KR (2014) A mini-anterior approach to the hip for total joint replacement: optimising results: improving hip joint replacement outcomes. Bone Jt J 96-b(11 Supple A):32–35. https://doi.org/10.1302/0301-620x.96b11.34348
34. Nakamura J, Hagiwara S, Orita S, Akagi R, Suzuki T, Suzuki M, Takahashi K, Ohtori S (2017) Direct anterior approach for total hip arthroplasty with a novel mobile traction table—a prospective cohort study. BMC Musculoskelet Disord 18(1):49. https://doi.org/10.1186/s12891-017-1427-2
35. Nakata K, Nishikawa M, Yamamoto K, Hirota S, Yoshikawa H (2009) A clinical comparative study of the direct anterior with mini-posterior approach: two consecutive series. J Arthroplasty 24(5):698–704. https://doi.org/10.1016/j.arth.2008.04.012
36. Oinuma K, Eingartner C, Saito Y, Shiratsuchi H (2007) Total hip arthroplasty by a minimally invasive, direct anterior approach. Oper Orthop Traumatol 19(3):310–326. https://doi.org/10.1007/s00064-007-1209-3
37. Panichkul P, Parks NL, Ho H, Hopper RH Jr, Hamilton WG (2016) New approach and stem increased femoral revision rate in total hip arthroplasty. Orthopedics 39(1):e86–e92. https://doi.org/10.3928/01477447-20151222-06
38. Patton RS, Runner RP, Lyons RJ, Bradbury TL (2018) Clinical outcomes of patients with lateral femoral cutaneous nerve injury after direct anterior total hip arthroplasty. J Arthroplasty. https://doi.org/10.1016/j.arth.2018.04.032
39. Perry CR Jr, Fahs AM, Kurdziel MD, Koueiter DM, Fayne RJ, Verner JJ (2018) Intraoperative psoas compartment block vs preoperative fascia iliaca block for pain control after direct anterior total hip arthroplasty: a randomized controlled trial. J Arthroplasty 33(6):1770–1774. https://doi.org/10.1016/j.arth.2018.01.010
40. Pogliacomi F, De Filippo M, Paraskevopoulos A, Alesci M, Marenghi P, Ceccarelli F (2012) Mini-incision direct lateral approach versus anterior mini-invasive approach in total hip replacement: results 1 year after surgery. Acta Bio-medica Atenei Parmensis 83(2):114–121
41. Ponzio DY, Poultsides LA, Salvatore A, Lee YY, Memtsoudis SG, Alexiades MM (2018) In-hospital morbidity and postoperative revisions after direct anterior vs posterior total hip arthroplasty. J Arthroplasty 33(5):1421–1425.e1421. https://doi.org/10.1016/j.arth.2017.11.053
42. Putananon C, Tuchinda H, Arirachakaran A, Wongsak S, Narinsorasak T, Kongtharvonskul J (2018) Comparison of direct anterior, lateral, posterior and posterior-2 approaches in total hip arthroplasty: network meta-analysis. 28(2):255–267. https://doi.org/10.1007/s00590-017-2046-1
43. Reichert JC, Volkmann MR, Koppmair M, Rackwitz L, Ludemann M, Rudert M, Noth U (2015) Comparative retrospective study of the direct anterior and transgluteal approaches for primary total hip arthroplasty. Int Orthop 39(12):2309–2313. https://doi.org/10.1007/s00264-015-2732-8
44. Restrepo C, Parvizi J, Pour AE, Hozack WJ (2010) Prospective randomized study of two surgical approaches for total hip arthroplasty. J Arthroplasty 25(5):671–679.e671. https://doi.org/10.1016/j.arth.2010.02.002
45. Rivera F, Leonardi F, Evangelista A, Pierannunzii L (2016) Risk of stem undersizing with direct anterior approach for total hip arthroplasty. Hip Int J Clin Exp Res Hip Pathol Therapy 26(3):249–253. https://doi.org/10.5301/hipint.5000337
46. Rodriguez JA, Deshmukh AJ, Rathod PA, Greiz ML, Deshmane PP, Hepinstall MS, Ranawat AS (2014) Does the direct anterior approach in THA offer faster rehabilitation and comparable safety to the posterior approach? Clin Orthop Relat Res 472(2):455–463. https://doi.org/10.1007/s11999-013-3231-0

47. Sariali E, Catonne Y, Pascal-Moussellard H (2017) Three-dimensional planning-guided total hip arthroplasty through a minimally invasive direct anterior approach. Clinical outcomes at five years' follow-up. Int Orthop 41(4):699–705. https://doi.org/10.1007/s00264-016-3242-z
48. Sendtner E, Borowiak K, Schuster T, Woerner M, Grifka J, Renkawitz T (2011) Tackling the learning curve: comparison between the anterior, minimally invasive (Micro-hip(R)) and the lateral, transgluteal (Bauer) approach for primary total hip replacement. Arch Orthop Trauma Surg 131(5):597–602. https://doi.org/10.1007/s00402-010-1174-4
49. Shemesh SS, Robinson J, Keswani A, Bronson MJ, Moucha CS, Chen D (2017) The accuracy of digital templating for primary total hip arthroplasty: is there a difference between direct anterior and posterior approaches? J Arthroplasty 32(6):1884–1889. https://doi.org/10.1016/j.arth.2016.12.032
50. Sheth D, Cafri G, Inacio MC, Paxton EW, Namba RS (2015) Anterior and anterolateral approaches for THA are associated with lower dislocation risk without higher revision risk. Clin Orthop Relat Res 473(11):3401–3408. https://doi.org/10.1007/s11999-015-4230-0
51. Simmonds MC, Higgins JP (2007) Covariate heterogeneity in meta-analysis: criteria for deciding between meta-regression and individual patient data. Stat Med 26(15):2982–2999. https://doi.org/10.1002/sim.2768
52. Tamaki T, Jonishi K, Miura Y, Oinuma K, Shiratsuchi H (2018) Cementless tapered-wedge stem length affects the risk of periprosthetic femoral fractures in direct anterior total hip arthroplasty. J Arthroplasty 33(3):805–809. https://doi.org/10.1016/j.arth.2017.09.065
53. Tamaki T, Oinuma K, Miura Y, Higashi H, Kaneyama R, Shiratsuchi H (2016) Epidemiology of dislocation following direct anterior total hip arthroplasty: a minimum 5-year follow-up study. J Arthroplasty 31(12):2886–2888. https://doi.org/10.1016/j.arth.2016.05.042
54. Taunton MJ, Mason JB, Odum SM, Springer BD (2014) Direct anterior total hip arthroplasty yields more rapid voluntary cessation of all walking aids: a prospective, randomized clinical trial. J Arthroplasty 29(9 Suppl):169–172. https://doi.org/10.1016/j.arth.2014.03.051
55. Thakkinstian A, McEvoy M, Minelli C, Gibson P, Hancox B, Duffy D, Thompson J, Hall I, Kaufman J, Leung TF, Helms PJ, Hakonarson H, Halpi E, Navon R, Attia J (2005) Systematic review and meta-analysis of the association between {beta}2-adrenoceptor polymorphisms and asthma: a HuGE review. Am J Epidemiol 162(3):201–211. https://doi.org/10.1093/aje/kwi184
56. Thompson SG, Higgins JP (2002) How should meta-regression analyses be undertaken and interpreted? Stat Med 21(11):1559–1573. https://doi.org/10.1002/sim.1187
57. Tsahtsarlis A, Wood M (2012) Minimally invasive transforaminal lumber interbody fusion and degenerative lumbar spine disease. Eur Spine J 21(11):2300–2305. https://doi.org/10.1007/s00586-012-2376-y
58. Varin D, Lamontagne M, Beaule PE (2013) Does the anterior approach for THA provide closer-to-normal lower-limb motion? J Arthroplasty 28(8):1401–1407. https://doi.org/10.1016/j.arth.2012.11.018
59. Watanabe K, Mitsui K, Usuda Y, Nemoto K (2019) An increase in the risk of excessive femoral anteversion for relatively younger age and types of femoral morphology in total hip arthroplasty with direct anterior approach. J Orthop Surg (Hong Kong) 27(2):2309499019836816. https://doi.org/10.1177/2309499019836816
60. Wayne N, Stoewe R (2009) Primary total hip arthroplasty: a comparison of the lateral Hardinge approach to an anterior mini-invasive approach. Orthop Rev 1(2):e27. https://doi.org/10.4081/or.2009.e27
61. Weale AE, Newman P, Ferguson IT, Bannister GC (1996) Nerve injury after posterior and direct lateral approaches for hip replacement. A clinical and electrophysiological study. J Bone Jt Surg Br 78(6):899–902
62. William B (2014) Response to "a tale of two approaches": prospective randomized study of direct anterior vs postero-lateral approach for total hip arthroplasty. J Arthroplasty 29(7):1507–1508. https://doi.org/10.1016/j.arth.2014.01.030
63. Witzleb WC, Stephan L, Krummenauer F, Neuke A, Gunther KP (2009) Short-term outcome after posterior versus lateral surgical approach for total hip arthroplasty—a randomized clinical trial. Eur J Med Res 14(6):256–263
64. Yang C, Zhu Q, Han Y, Zhu J, Wang H, Cong R, Zhang D (2010) Minimally-invasive total hip arthroplasty will improve early postoperative outcomes: a prospective, randomized, controlled trial. Ir J Med Sci 179(2):285–290. https://doi.org/10.1007/s11845-009-0437-y
65. Zawadsky MW, Paulus MC, Murray PJ, Johansen MA (2014) Early outcome comparison between the direct anterior approach and the mini-incision posterior approach for primary total hip arthroplasty: 150 consecutive cases. J Arthroplasty 29(6):1256–1260. https://doi.org/10.1016/j.arth.2013.11.013
66. Zhao HY, Kang PD, Xia YY, Shi XJ, Nie Y, Pei FX (2017) Comparison of early functional recovery after total hip arthroplasty using a direct anterior or posterolateral approach: a randomized controlled trial. J Arthroplasty 32(11):3421–3428. https://doi.org/10.1016/j.arth.2017.05.056

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