Comparison of Direct Anterior and Lateral Approaches in Total Hip Arthroplasty

A Systematic Review and Meta-Analysis (PRISMA)

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Abstract: The direct anterior approach (DAA) to total hip arthroplasty has been promoted as a minimally invasive alternative to the lateral approach, which we sought to verify by systematically reviewing and meta-analyzing the literature comparing clinical, radiographic, and surgical outcomes.

Two reviewers independently searched PubMed, OVID, and Web of Science databases for randomized controlled trials (RCTs) and cohort studies comparing the DAA and lateral approach for total hip arthroplasty.

Quality of RCTs was assessed using the Jadad scoring system, quality of cohort studies, using the Minors system. Data were extracted and meta-analyzed or qualitatively synthesized for primary outcomes (function, complications, and hospitalization time) and several secondary outcomes.

Data were extracted from 12 trials involving 4901 arthroplasty procedures. Meta-analysis showed that DAA was associated with significantly shorter hospitalization than the lateral approach, as well as greater functional rehabilitation and lower perceived pain during the early postoperative period. On the other hand, DAA was associated with longer surgery time. The 2 approaches were associated with similar rates of perioperative surgical complications and transfusions, as well as similar radiographic analysis results.

Although DAA may provide shorter hospitalization and faster recovery during the early postoperative period, the available evidence is still insufficient to conclude whether the DAA or lateral approach is superior for total hip arthroplasty. More high-quality studies and subsequent meta-analyses are needed.
Specifically, we systematically reviewed randomized controlled trials (RCTs) and cohort studies comparing the DAA and lateral approach for total hip arthroplasty, and we meta-analyzed available data on a total of 9 categories of outcomes: functions, complications, length of stay, radiographic analysis, transfusions, pain, markers of muscle damage and inflammation, surgery time, and gait.

**METHODS**

Ethical approval for this study was deemed unnecessary because it was a review of existing literature and did not involve any handling of individual patient data.

**Search Methodology**

Two reviewers (CY and PDK) independently searched PubMed, OVID, and Web of Science databases in June 2015 without restrictions on publication date or language. Search terms included “total hip replacement,” “total hip arthroplasty,” “THA,” “THR,” “anterior,” “direct anterior,” “anterior supine intermuscular,” “Hueter approach,” and “Smith-Petersen.” Search terms were combined using the Boolean operators “AND” or “OR.” Reference lists of relevant articles were manually searched to identify additional trials.

**Selection Criteria**

A study was considered eligible for inclusion if it was an RCT or cohort study, compared DAA with a lateral approach, and reported data for at least one of the following outcomes: postoperative function, complications, hospitalization time, radiographic analysis, transfusion, pain, markers of muscle damage or inflammation, surgery time, and gait.

Studies were excluded from consideration if they were explicitly labeled as a “pilot study;” were based on a cross-sectional questionnaire, case report, or frozen cadavers; or involved bilateral total hip arthroplasty, hemiarthroplasty, or computed tomography-based or robot-assisted total hip arthroplasty.

**Literature Selection**

All potentially relevant studies were imported into Endnote X6 and duplicates were excluded. Then the 2 researchers who had searched the databases excluded studies based on titles and abstracts. The 2 researchers read the full text of the remaining studies and excluded those that did not satisfy the selection criteria. Disagreements were resolved by discussion with a third researcher (FXP).

**Data Extraction**

The same 2 researchers independently extracted the following data from the final set of included studies: first author’s name, country, publication year, any significant differences at baseline, sample size, follow-up period, and whether DAA surgeons were still on a learning curve. Data were also collected on the following primary outcomes: postoperative function, complications, and hospitalization time. Function and complications were selected as primary outcomes because they directly reflect efficacy and safety of the surgical approach. Hospitalization time was selected because it is one of the strongest determinants of rapid recovery after total hip arthroplasty, and it is therefore closely related to patient costs and satisfaction.

Data were also collected on the following secondary outcomes: radiographic analysis, transfusion, pain, markers of muscle damage and inflammation, surgery time, and gait. Table 1 provides detailed descriptions of each outcome.

**TABLE 1. The Detailed Description of Each Outcome Assessment**

| Outcomes                  | Detailed Description                                                                 |
|---------------------------|---------------------------------------------------------------------------------------|
| Primary outcomes          | Refer to perioperative surgical complications, including dislocation, intraoperative fracture, nerve palsy, cutaneous nerve palsy, superficial infection, deep infection, and postoperative hematoma |
| Complications             |                                                                                      |
| Functions                 | Evaluated with functional scales, including HHS, SF-36, UCLA, DAQ, WOMAC, LEFS, and LASA, or evaluated the range of motion |
| Length of stay            | Inpatient days, “Day” as the unit, no special description                              |
| Secondary outcomes        |                                                                                      |
| Radiographic analysis     | Including the degrees of inclination and anteversion, and the stem positioning        |
| Transfusions              | Transfusion rate, no special description                                              |
| Pain                      | Evaluated with pain scoring scales, including VAS and NRS                             |
| Surgery time              | “Minute” as the unit, no special description                                          |
| Markers of inflammation   | Serum markers of inflammation and muscle damage, including CK and CRP                 |
| and muscle damage         |                                                                                      |
| Gait                      | Gait based on spatiotemporal gait analysis                                            |

CK = creatine kinas, CRP = C-reactive protein, DAQ = Daily Activity Questionnaire, HHS = Harris Hip Score, LASA = Linear Analog Scale Assessment, LEFS = Lower Extremity Function Scale, NRS = Numerical Rating Scale, SF-36 = Medical Outcome Survey Short-Form 36, UCLA = University of California, Los Angeles activity score, VAS = Visual Analog Score, WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.

**Assessment of Study Quality**

Working independently, 2 researchers (CY and PDK) assessed the quality of included RCTs using the Jadad scoring system. This system assesses randomization, blinding, withdrawals, and dropouts, awarding a study a score of 0–5 points. The quality of cohort studies was assessed using the Minors scoring system, which is considered suitable for nonrandomized surgical intervention studies. This system awards a score of 0–2 points for each of 12 items according to whether the item was reported or not and whether it was treated adequately or not (see Supplemental Table, Supplemental Content, http://links.lww.com/MD/A557, which provides a detailed description of the Jadad and Minors scales). Discrepancies between assessments by the 2 reviewers were resolved by discussion, with arbitration by a 3rd reviewer when necessary.

**Statistical Analysis**

Outcomes for which data could not be compared directly across studies were synthesized qualitatively, as were outcomes.
for which insufficient data were reported across studies. Outcomes for which sufficient, equivalent data were reported across studies were meta-analyzed using Forest plots generated with RevMan 5.2. Dichotomous data were expressed as proportions, such as rates of transfusions and complications; the intervention effect was expressed as a risk ratio. Continuous data reported in the same way across studies, such as for hospitalization time, were meta-analyzed in terms of the weighted mean difference (WMD) and associated 95% confidence interval (95%CI). Continuous data reported in different ways across studies were meta-analyzed in terms of the standardized mean difference (SMD). Continuous data reported as medians and ranges were transformed into means and standard deviations using Hozo formula.24

Pooled data were assessed for heterogeneity using the Chi-squared test and I² tests. Heterogeneity was defined as absent when I² was between 0 and 25%; low, between 25.1% and 50%; moderate, between 50.1% and 75%; or high, between 75.1% and 100%. Fixed-effects meta-analysis was performed when \( P \geq 0.1 \) and \( I^2 \leq 50\%; \) otherwise, random-effects meta-analysis was performed.

RESULTS

Search Results

Systematic search of Pubmed, OVID, and Web of Science turned up 4286 potentially eligible studies, and no additional records were found during manual searches of reference lists (See Supplemental Figures 1–3, Supplemental Contents, http://links.lww.com/MD/A557, which illustrates the detailed search histories for each electronic database). After removing 1775 duplicate studies using Endnote X6, another 2354 studies were excluded based on their titles and abstracts. The remaining 157 studies were read in full, and 145 were excluded because they failed to satisfy the selection criteria. In the end, 12 studies were included in the systematic review and meta-analysis. Details of study identification, screening, and selection are given in Figure 1.

Characteristics of Included Studies

The included 12 studies were performed within the last 6 years, altogether involving 2991 cases of DAA total hip arthroplasty and 1910 cases of lateral approach total hip arthroplasty. Three studies were performed in the US, 3 in Germany, 2 in Norway, 2 in Italy, and 1 each in Canada and Switzerland.

Minors quality scores for the 10 cohort studies ranged from 10 to 18 points of a possible 24, while Jadad quality scores for the 2 RCTs were 326 and 4 points25 of a possible 5. Eleven studies compared the DAA and lateral groups at baseline, and 9 studies found no significant differences.17–19,25–26,29–33 Seven studies carried out short- or intermediate-term follow-up lasting up to 1 year,18–19,26,29–32 Another study evaluated patients only at 6 weeks,28 and another 4 reported clinical outcomes only.

FIGURE 1. Flowchart of study selection.
during postoperative hospitalization.\textsuperscript{17,25,27,33} Seven studies evaluated postoperative function.\textsuperscript{18–19,26–30} 6 studies used patient-reported functional scales, and 1 study reported range of motion.\textsuperscript{27} Eight studies reported perioperative surgical complications.\textsuperscript{17–19,26,29–31,33} Six studies provided data on hospitalization time.\textsuperscript{17,26–29,33} Only 1 study each analyzed postoperative gait\textsuperscript{32} or assayed levels of markers of muscle damage and inflammation.\textsuperscript{25} Three studies explicitly stated that surgeons performed DAA while still on the learning curve,\textsuperscript{18,30,33} while 4 stated that the DAA surgeons had completed the learning curve.\textsuperscript{19,25,26,29} The remaining 5 studies did not explicitly mention a learning curve. Detailed study quality assessment and outcomes data can be found in Tables 2–4.

**PRIMARY OUTCOMES**

**Postoperative Function**

Seven studies involving 1560 cases of total hip arthroplasty reported functional outcomes,\textsuperscript{18–19,26–30} (Table 5), though functional scales and follow-up periods varied substantially. Four of the 7 studies showed that DAA led to better functional outcomes.\textsuperscript{18,26–28} Mirza et al\textsuperscript{28} reported significantly higher 6-week Harris Hip Score (HHS) scores with DAA ($P < 0.0001$). Restrepo et al\textsuperscript{26} found that DAA led to significantly better scores on the HHS, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Short Form 36-Item Health Survey scale, Lower Extremity Functional Score, and Linear Analog Scale Assessment at 6 weeks, 6 months, and 1 year, although DAA and the lateral approach led to similar scores on these instruments at 2 years. Similarly, Ilchmann et al\textsuperscript{18} found significantly higher HHS scores with DAA at 6 weeks, 12 weeks, and 1 year, but similar HHS scores for DAA and the lateral approach at 2 years. Goebel et al\textsuperscript{27} found that mean time to achieve the therapeutic goal was shorter in the DAA group (6.4 vs 7.4 days).

In contrast, 3 studies found no significant differences in functional outcomes between DAA and the lateral approach at 1 year\textsuperscript{29–30} or 3.7 year.\textsuperscript{19}

**Perioperative Complications**

Eight studies reported the occurrence of 7 types of perioperative surgical complications.\textsuperscript{17–19,26,29–31,33} Meta-analysis showed that both DAA and the lateral approach were associated with similar risk of dislocation, intraoperative fracture, nerve palsy, superficial infection, deep infection, and postoperative hematoma (Table 6). In contrast, DAA was associated with higher risk of cutaneous nerve palsy (RR 5.69, 95%CI 1.06–30.62, $P = 0.04$).

**Hospitalization Time**

Six studies reported data on this outcome.\textsuperscript{17,26–29,33} Meta-analysis showed that hospitalization time after DAA was shorter by a mean of 1.19 days (95%CI -2.08 to 0.3, $P = 0.009$) than after the lateral approach (Fig. 2). This meta-analysis involved a random-effects model because of significant heterogeneity among the studies ($I^2 = 96\%$).

**Secondary Outcomes**

DAA and lateral approach groups showed similar rates of transfusion (RR 0.78, 95%CI 0.60–1.02, $P = 0.07$; Fig. 3), while surgery time was longer with DAA by a WMD of 7.99 min (95%CI 2.38–13.6, $P = 0.005$; Fig. 4). Radiographic analyses indicated that the 2 approaches were associated with similar degrees of inclination (WMD 0.00°, 95%CI –1.15 to 1.15, $P = 1.00$) and anteversion (WMD 3.05°, 95% CI –6.65 to 12.75, $P = 0.54$) (Figs. 5–6), as well as similar rates of varus or valgus stem positioning (RR 0.92, 95%CI 0.68–1.26, $P = 0.62$; Fig. 7).

### TABLE 2. Minors Score for Each Included Nonrandomized Study and Jadad Score for Each Included Randomized Study

| First Author, year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
|--------------------|---|---|---|---|---|---|---|---|---|----|----|----|------|
| Mirza (2014)\textsuperscript{28} | 2 | 1 | 0 | 2 | 0 | 2 | 1 | 0 | 2 | 2 | 0 | 2 | 14  |
| Reichert (2015)\textsuperscript{19} | 2 | 2 | 0 | 2 | 0 | 2 | 2 | 0 | 2 | 2 | 0 | 2 | 16  |
| Varin (2013)\textsuperscript{32} | 2 | 0 | 0 | 2 | 0 | 2 | 2 | 0 | 2 | 2 | 0 | 2 | 12  |
| Wayne (2009)\textsuperscript{33} | 2 | 2 | 0 | 2 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 2 | 12  |
| Ilchmann (2013)\textsuperscript{18} | 2 | 2 | 2 | 2 | 0 | 2 | 0 | 0 | 2 | 0 | 2 | 0 | 14  |
| Goebel (2012)\textsuperscript{27} | 2 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 10  |
| Sendtner (2011)\textsuperscript{30} | 2 | 1 | 2 | 2 | 0 | 2 | 0 | 0 | 2 | 0 | 2 | 0 | 15  |
| Pogliacomi (2012)\textsuperscript{29} | 2 | 2 | 0 | 2 | 0 | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 18  |
| Aleczi (2011)\textsuperscript{37} | 2 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 14  |
| Sheth (2015)\textsuperscript{31} | 2 | 1 | 2 | 2 | 0 | 2 | 1 | 0 | 2 | 2 | 2 | 2 | 18  |

| First Author, year | Randomized | Blinded | Withdrawal | Total |
|--------------------|------------|---------|------------|-------|
| Mjaaland (2015)\textsuperscript{25} | 2 | 1 | 1 | 4 |
| Restrepo (2010)\textsuperscript{26} | 2 | 0 | 1 | 3 |

Numbers 1–12 in heading signified: 1, a clearly stated aim; 2, inclusion of consecutive patients; 3, prospective collection of data; 4, endpoints appropriate to the aim of the study; 5, unbiased assessment of the study endpoint; 6 follow-up period appropriate to the aim of the study; 7 loss to follow-up less than 5%; 8 prospective calculation of the study size; 9 an adequate control group; 10 contemporary groups; 11 baseline equivalence of groups; and 12, adequate statistical analyses.
Six studies evaluated postoperative pain using pain scales, though the scales and evaluation time points varied considerably. Four studies reported significantly better pain scores after DAA. One RCT by Mjaaland et al and 1 cohort study by Goebel et al associated DAA with lower scores on the visual analogue scale during postoperative hospitalization. Alecci et al found a lower pain score on the numerical rating scale (NRS) on the first day after DAA (1.4 vs 2.5 points). Ilchmann et al reported lower visual analogue scale pain scores in the DAA group at 6 and 12 weeks. The remaining 2 studies found no significant differences in pain scores between groups at 1 year or 3.7 years.

One study compared DAA and the lateral approach in terms of postoperative serum levels of creatine kinase and C-reactive protein, which serve as markers of inflammation and muscle damage. Creatine kinase levels immediately after arthroplasty and on postoperative day 4 were significantly higher in the DAA group, while C-reactive protein levels were similar between the 2 groups at all time points examined. One study compared the 2 approaches using spatiotemporal gait analysis and found no significant difference.

**DISCUSSION**

This is the first systematic review and meta-analysis to compare DAA and lateral approach total hip arthroplasty in terms of clinical, radiographic, and surgical outcomes. The available evidence suggests that DAA may be associated with better early postoperative functional rehabilitation, lower levels of perceived pain, and shorter hospitalization time. On the other hand, DAA may be associated with longer surgery time. The 2 arthroplasty approaches appear to be associated with similar rates of perioperative surgical complications and transfusion, similar results on radiographic and gait analyses, and similar serum levels of inflammation and muscle damage markers. We conclude that the available evidence does not allow us to determine whether DAA or the lateral approach is superior; more large, well-designed studies are needed to explore the results of this meta-analysis in greater detail.

In theory, many clinicians perform DAA because it avoids the inevitable muscle-splitting in the lateral approach, which can prolong hospitalization and complicate functional rehabilitation in the early postoperative period. DAA, in contrast, does not require exposing or lacerating the gluteus minimus and medius muscles. Although DAA can damage the tensor fascia lata, this may have only a minor effect on early rehabilitation. As a result, DAA can lead to more rapid functional recovery and shorter hospitalization times than other approaches.

Our meta-analysis of available clinical evidence suggests that in practice, the benefits of DAA over the lateral approach are less clear. Although several studies in our systematic review consistently showed better outcomes with DAA during functional rehabilitation within 1 year of surgery, including a reduction in mean hospitalization stay by more than 1 day, other studies failed to show any differences in functional recovery at follow-up times beyond 1 year. It may be that the benefits of DAA occur primarily during the early postoperative period. Consistent with this idea, numerous studies in our systematic review reported significantly lower levels of perceived pain after DAA within early postoperative period. These results may help explain why several studies have reported more rapid functional rehabilitation with DAA.

Although some studies have associated DAA with fairly low complication rates, others have reported fairly high

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**TABLE 3. Characteristics of Included Studies**

| First Author, year | Country | Difference in Baseline | Follow-up | DAA in Learning Curve | Sample Sizes (DAA vs LA) | Study Type |
|--------------------|---------|------------------------|-----------|-----------------------|--------------------------|------------|
| Mirza (2014)       | USA     | Lower BMI in DAA group | 6 weeks   | DAA: 5 years          | 630 (258 vs 372)          | Co, R      |
| Reichert (2015)    | Germany | None                   | 6 weeks   | DAA: 5 years          | 171 (85 vs 86)           | Co, R      |
| Mjaaland (2015)    | Norway  | None                   | 1 year    | Hospitalization       | 40 (50 vs 50)            | Co, P      |
| Varin (2013)       | Canada  | None                   | 2 years   | Hospitalization       | 205 (100 vs 100)         | Co, R      |
| Restrepo (2010)    | USA     | None                   | 1 year    | Hospitalization       | 25 (74 vs 60)            | Co, P      |
| Wayne (2009)       | USA     | Younger and lower BMI in DAA group | 3 years | Hospitalization       | 255 (13 vs 12)           | Co, R      |
| Goebel (2012)      | Germany | None                   | 1 year    | Hospitalization       | 70 (35 vs 35)            | Co, R      |
| Sondheimer (2011)  | Italy   | None                   | 2 years   | Hospitalization       | 451 (253 vs 198)         | Co, R      |
| Pogliacomi (2012)  | Italy   | None                   | 1 year    | Hospitalization       | 25 (8 vs 18)             | Co, R      |
| Sheth (2015)       | USA     | None                   | 3 years   | Hospitalization       | 255 (13 vs 12)           | Co, R      |

Co = Cohort study, DAA = direct anterior approach, LA = lateral approach, P = prospective study, RCT = randomized control trial.
Our meta-analysis suggests that the rates of most complications are similar for DAA and the lateral approach, with at least 1 exception: risk of cutaneous nerve palsy is 5.69-fold higher with DAA. This cutaneous nerve palsy is likely to come from the lateral femoral cutaneous nerve, but none of the studies reporting this complication described it in sufficient detail to indicate whether it referred only to skin numbness lateral to the incision or to complete nerve palsy of the entire lateral thigh. This is an important question because many clinicians do not consider skin numbness a complication of total hip arthroplasty unless it is particularly bothersome to the patient. We suggest that our meta-analysis finding of greater

| First author, year | Outcome Assessments | Summary of Significantly Different Outcomes Between Groups | Tendentious Choice |
|---------------------|---------------------|----------------------------------------------------------|-------------------|
| Mirza (2014)28      | F, L, S, T          | A higher HHS in DAA group at 6 weeks after surgery.     | Ambiguous         |
| Reichert (2015)19   | C, F, P, R          | No significant difference.                               | Neither            |
| Mjaaaland (2015)25  | S, M, P, T          | DAA causes less pain but higher postoperative levels of CK. | Ambiguous         |
| Varin (2013)32      | G                   | No significant difference in gait analysis.              | Neither            |
| Restrepo (2010)26   | C, F, L, S, T       | A better functional outcomes in DAA group at 6w, 6m and 1 y follow-up, but no difference at 2 y follow-up. | Ambiguous         |
| Wayne (2009)33      | C, S, L, R, T       | DAA causes more bleeding, nerve damage, and acetabular component malposition whilst having a shorter LOS and fewer infections. | Ambiguous         |
| Ilchmann (2013)18   | C, F, L, R, S, T    | DAA causes a longer surgery time, but the functional outcomes are better than LA at 6w, 12w and 1y follow-up. | DAA               |
| Goebel (2012)27     | F, L, P             | Significant pain relief, faster functional recovery and earlier discharge in DAA group. | Ambiguous         |
| Sendtner (2011)30   | C, F, R, S, T       | Less bleeding whilst a longer surgery time in DAA group. | Ambiguous         |
| Pogliaocimi (2012)29| C, F, L, P, R, S, T| No significant difference.                               | Neither            |
| Alecci (2011)17     | C, L, S, P, T       | Less pain, bleeding and LOS whilst a longer surgery time in DAA group. | Ambiguous         |
| Sheth (2015)31      | C                   | No significant difference in dislocation rate between DAA and LA. | Neither            |

C = complications, DAA = direct anterior approach, F = functions, G = gait, L = length of stay, LA = lateral approach, LOS = length of stay, M = makers of muscle damage and inflammation, P = pain, R = radiographic analysis, S = surgery time, T = transfusions.

| Author               | Follow-Up Period | Functional Scale Types and Results Summary | Superiority |
|----------------------|------------------|-------------------------------------------|-------------|
| Mirza (2014)28       | 6 week           | HHS: A higher HHS in DAA group at 6-week follow-up. | DAA         |
| Reichert (2015)19    | DAA: 3.7 year DLA: 5.5 year | HHS, SF-36, UCLA, DAQ no any difference in each functional scale. | Neither     |
| Restrepo (2010)26    | 6 weeks, 6 months, 1 year, and 2 years | HHS, WOMAC, SF-36, LEFS, LASA no any difference in each functional scale at 2-year follow-up, but a higher score in DAA group at 6 weeks, 6 months, and 1-year follow-up. | DAA         |
| Ilchmann (2013)18    | 6 weeks, 12 weeks, 1 year, and 2 years | HHS: no difference at 2-year follow-up, but a higher score in DAA group at 6 weeks, 12 weeks, and 1-year follow-up. | DAA         |
| Goebel (2012)27      | Inpatient days   | Range of motion: DAA group had shorter time (mean 6.4 days) to achieve the therapeutic goal than LA group (mean 7.4 days). | DAA         |
| Sendtner (2011)30    | 1 year           | HHS: the same of 92 points at 1-year follow-up. | Neither     |
| Pogliaocimi (2012)29 | 1 year           | HHS: no difference at 1-year follow-up. | Neither     |

DAA = direct anterior approach, DAQ = Daily Activity Questionnaire, HHS = Harris Hip Score, LA = lateral approach, LASA = Linear Analog Scale Assessment, LEFS = Lower Extremity Functional Score, SF-36 = Medical Outcome Survey Short-Form 36, UCLA = University of California, Los Angeles activity score, WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.
risk of cutaneous nerve palsy with DAA may not be clinically significant, and further study is needed to examine this in greater detail.

The study by Mjaaland et al\textsuperscript{25} in our systematic review reported similar serum levels of C-reactive protein in patients treated by DAA or lateral approach, which is consistent with another study not included in our systematic review because it compared DAA with a posterior approach.\textsuperscript{39} These results may mean that the inflammatory cascade associated with total hip arthroplasty is influenced primarily by bone removal and implant placement, not by the surgical approach.\textsuperscript{39} Mjaaland et al\textsuperscript{25} also reported higher serum levels of creatine kinase in patients with DAA, which does not make sense given the observed similarity in C-reactive protein levels. Those authors suggested that this result was due to a type 2 error.

Unfortunately, our meta-analysis was unable to isolate the influence of the DAA learning curve on the results. It is difficult to estimate what proportion of DAA total hip arthroplasties in our systematic review were performed within or beyond the curve, since studies not included in our systematic review have reported 30 to 200 DAA procedures beyond the learning curve.\textsuperscript{35,40,41} Only 7 of the 12 trials in our review explicitly

| Complications                  | Studies (n) | Patients (n) | P-Value | Risk Ratio (95% CI) | Heterogeneity ($I^2$), % | Model |
|-------------------------------|-------------|--------------|---------|---------------------|--------------------------|-------|
| Dislocation                   | 6           | 3377         | 0.77    | 1.15 [0.44, 3.04]   | 0                        | Fixed |
| Intraoperative fracture       | 6           | 1282         | 0.25    | 1.53 [0.74, 3.16]   | 17                       | Fixed |
| Nerve palsy                   | 4           | 708          | 0.14    | 2.59 [0.70, 9.58]   | 39                       | Fixed |
| Cutaneous nerve palsy*        | 3           | 408          | 0.04    | 5.69 [1.06, 30.62]  | 0                        | Fixed |
| Superficial infection         | 4           | 604          | 0.68    | 0.76 [0.22, 2.71]   | 44                       | Fixed |
| Deep infection                | 5           | 963          | 0.58    | 0.7 [0.19, 2.53]    | 40                       | Fixed |
| Postoperative hematoma        | 4           | 659          | 0.99    | 0.96 [0.32, 2.92]   | 0                        | Fixed |

*The difference is statistically significant.

FIGURE 2. Forest plot of hospitalization time for patients after DAA or lateral approach total hip arthroplasty. DAA = direct anterior approach, df = degrees of freedom, IV = inverse variance, random = random-effects modeling, SD = standard deviation.

FIGURE 3. Forest plot of transfusion rates among patients after DAA or lateral approach total hip arthroplasty. DAA = direct anterior approach, df = degrees of freedom, fixed = fixed-effects modeling, M-H = Mantel–Haenszel.
FIGURE 4. Forest plot of surgery time for patients receiving DAA or lateral approach total hip arthroplasty. DAA = direct anterior approach, df = degrees of freedom, IV = inverse variance, random = random-effects modeling, SD = standard deviation.

| Study or Subgroup | DAA Mean | SD | Total | Mean | SD | Total | Weight | Mean Difference IV, Random, 95% CI |
|-------------------|----------|----|-------|------|----|-------|--------|----------------------------------|
| Alecci 2011       | 89.1     | 19 | 221   | 81   | 15 | 198   | 18.1%  | 8.00 [4.74, 11.26]                |
| Mjalland 2015     | 77.13    | 35 | 94    | 62   | 7.2 | 80    | 18.1%  | -15.00 [11.71, 19.29]             |
| Pogliaciomi 2012  | 90.11    | 11.75 | 35 | 91.9  | 13.41 | 35 | 15.9%  | -1.80 [-7.71, 4.11]               |
| Restrepo 2010     | 56.42    | 9.2 | 50    | 54.88 | 10.7 | 50    | 17.6%  | 1.54 [2.37, 5.45]                 |
| Sendtner 2011     | 77.16    | 74 | 69    | 25   | 60  | 45.4%  | 8.00 [0.70, 15.30]                |
| Wayne 2009        | 115.25   | 100 | 98    | 17.5 | 100 | 15.7%  | 17.00 [10.94, 23.08]              |
| Total             | 564      | 523 | 100%  | 7.99 [2.38, 13.60] |

Heterogeneity: Tau² = 42.49, Chi² = 46.49, df = 5 (P = 0.00001); I² = 99%
Test for overall effect: Z = 2.79 (P = 0.005)

FIGURE 5. Forest plot of radiographic inclination angle in patients after DAA or lateral approach total hip arthroplasty. DAA = direct anterior approach, df = degrees of freedom, IV = inverse variance, random = random-effects modeling, SD = standard deviation.

| Study or Subgroup | DAA Mean | SD | Total | Mean | SD | Total | Weight | Mean Difference IV, Random, 95% CI |
|-------------------|----------|----|-------|------|----|-------|--------|----------------------------------|
| Iltzmann 2013     | 39.8     | 5.9 | 113   | 37.7 | 6.8 | 142   | 20.4%  | 2.10 [0.54, 3.66]                 |
| Pogliaciomi 2012  | 46.1     | 2.68 | 35 | 46.78  | 3.02 | 35 | 22.6%  | -0.67 [-2.01, 0.67]               |
| Reichert 2015     | 37.6     | 3.9 | 85    | 37.6  | 5.1 | 86    | 22.4%  | 0.00 [-1.36, 1.36]                |
| Sendtner 2011     | 47.3     | 7.2 | 74    | 49.7 | 7.8 | 60    | 14.0%  | -2.00 [-4.32, 0.32]               |
| Wayne 2009        | 44.5     | 5.8 | 100   | 44    | 5.2 | 100   | 20.7%  | 0.00 [-1.53, 1.53]                |
| Total             | 407      | 423 | 100%  | -0.00 [-1.15, 1.15] |

Heterogeneity: Tau² = 1.06, Chi² = 10.74, df = 4 (P = 0.03); I² = 63%
Test for overall effect: Z = 0.01 (P = 1.00)

FIGURE 6. Forest plot of radiographic anteversion angle in patients after DAA or lateral approach total hip arthroplasty. DAA = direct anterior approach, df = degrees of freedom, IV = inverse variance, random = random-effects modeling, SD = standard deviation.

| Study or Subgroup | DAA Mean | SD | Total | Mean | SD | Total | Weight | Mean Difference IV, Random, 95% CI |
|-------------------|----------|----|-------|------|----|-------|--------|----------------------------------|
| Iltzmann 2013     | 21.8     | 8  | 113   | 23.7 | 7.5 | 142   | 50.0%  | -1.90 [3.82, 0.02]                |
| Wayne 2009        | 24.6     | 6.3 | 100   | 16.7 | 2.2 | 100   | 50.0%  | 8.00 [6.12, 9.88]                 |
| Total             | 241      | 242 | 100%  | 3.05 [-6.65, 12.75] |

Heterogeneity: Tau² = 48.07, Chi² = 52.19, df = 1 (P = 0.00001); I² = 99%
Test for overall effect: Z = 0.62 (P = 0.54)

FIGURE 7. Forest plot of rates of varus/valgus stem positioning in radiographic analysis of patients after DAA or lateral approach total hip arthroplasty. DAA = direct anterior approach, df = degrees of freedom, fixed = fixed-effects modeling, M-H = Mantel–Haenszel.

| Study or Subgroup | Events | Total | DAA Events | Total | LA Events | Total | Weight | Risk Ratio M-H, Fixed, 95% CI |
|-------------------|--------|-------|------------|-------|------------|-------|--------|-------------------------------|
| Pogliaciomi 2012  | 3      | 35    | 3          | 35    | 35         | 5.0%  | 1.00 [0.22, 4.62]            |
| Reichert 2015     | 6      | 85    | 6          | 86    | 6          | 9.9%  | 1.01 [0.34, 3.01]            |
| Sendtner 2011     | 22     | 74    | 22         | 60    | 60         | 40.3% | 0.81 [0.50, 1.31]            |
| Wayne 2009        | 27     | 100   | 27         | 100   | 100        | 44.8% | 1.00 [0.63, 1.58]            |
| Total             | 58     | 281   | 58         | 281   | 281        | 100%  | 0.92 [0.68, 1.26]            |

Total events: 58
Heterogeneity: Chi² = 0.43, df = 3 (P = 0.93); I² = 0%
Test for overall effect: Z = 0.49 (P = 0.62)
addressed the learning curve, preventing us from performing subgroup meta-analyses. This is an important limitation in other meta-analyses of DAA as well.\textsuperscript{21,41} The results of our meta-analysis may also reflect confounding by other factors such as patient characteristics\textsuperscript{42} and perioperative management.\textsuperscript{3} We were unable to control for these factors because of incomplete reporting by the studies in our review.

In summary, our study preliminary shows that although DAA may provide shorter hospitalization and faster recovery during the early postoperative period, the available evidence is still insufficient to conclude whether the DAA or lateral approach is superior for total hip arthroplasty. Our results highlight the need for large, high-quality studies that investigate outcomes of DAA and that can be incorporated into future meta-analyses.

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