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The learning curve of the direct anterior approach is 100 cases: an analysis based on 15,875 total hip arthroplasties in the Dutch Arthroplasty Register

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Background and purpose — In the last decade, the direct anterior approach (DAA) for total hip arthroplasty (THA) has become more popular in the Netherlands. Therefore, we investigated the learning curve and survival rate of the DAA in primary THA, using data from the Dutch Arthroplasty Register (LROI).

Patients and methods — We identified all patients who received a primary THA using the DAA in several high-volume centers in the Netherlands between 2007 and 2019 (n = 15,903). Procedures were ordered per surgeon, using date of operation. Using the procedure number, operations were divided into 6 groups based on the number of previous procedures per surgeon (first 25, 26–50, 51–100, 101–150, 151–200, > 200). Data from different surgeons in different hospitals was pooled together. Revision rates were calculated using a multilevel time-to-event analysis.

Results — Patients operated on in group 1–25 (hazard ratio [HR] 1.6; 95% CI 1.1–2.4) and 26–50 (HR 1.6; CI 1.1–2.5) had a higher risk for revision compared with patients operated on in group > 200 THAs. Between 50 and 100 procedures the revision risk was increased (HR 1.3; CI 0.9–1.9), albeit not statistically significant. From 100 procedures onwards the HR for revision was respectively 1.0 (CI 0.6–1.6) and 0.8 (CI 0.5–1.4) for patients in operation groups 101–150 and 151–200. Main reasons for revision were loosening of the stem (29%), periprosthetic infection (19%), and dislocation (16%).

Interpretation — We found a 64% increased risk of revision for patients undergoing THA using the DAA for the first 50 cases per surgeon. Between 50 and 100 cases, this risk was 30% increased, but not statistically significant. From 100 cases onwards, a steady state had been reached in revision rate. The learning curve for DAA therefore is around 100 cases.

The decision on surgical approach to perform a THA is predominantly determined by the surgeon's preference and local hospital standards, given the lack of compelling evidence in favor of one approach (1-4).

In the Netherlands, the posterolateral (PL) approach is the most frequently used approach (50% in 2020) for primary THA. However, in the last decade the direct anterior approach (DAA) has become more popular, while the use of direct lateral (DL) and anterolateral approaches diminished. In 2010, the DAA was used in 5% of cases compared with 41% in 2020 (5). A similar trend was seen in Norway, where the PL approach is most frequently used (72%), with a gradual increase in the DAA over the last 5 years (9.3% in 2021). In contrast, in Sweden the PL (59%) and DL in lateral (32%) or supine (8.4%) position have been dominant since 2005 (6-7).

Potential benefits of the DAA include early mobilization, reduced postoperative length of stay, and low dislocation rates (1-2,8). Conflicting data exists as to whether this technique is

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associated with a lower risk of revision due to dislocation and whether it is muscle-sparing (**3,9-11**). However, the approach is technically demanding with a significant learning curve even for experienced surgeons (**12-15**). Furthermore, DAA seems to be associated with increased risk of femoral stem revision (e.g., loosening and periprosthetic femoral fracture [PFF]) in the medium term (**9,16-18**). Lastly, femoral exposure might be difficult, and damage to the lateral femoral cutaneous nerve (LFCN) has been described (**19-20**).

For surgeons considering a switch to DAA, it is important to know how long their expected learning curve will be before reaching a steady state. There is no consensus on the length of this learning curve for experienced surgeons. Therefore, we investigated the learning curve and survival rate of the DAA using LROI data.

Patients and methods

Data collection

The LROI collects data on all patients undergoing THA in the Netherlands since 2007. The LROI covers all Dutch hospitals, which has resulted in a completeness of > 98% for primary THAs since 2010, with high validity of the data (**5,21**). As surgeons are blinded in the LROI and the number of surgeons per hospital cannot be assessed, we were unable to assess the learning curve for the DAA on a nationwide scale. Therefore, we started a collaboration with 6 high-volume DAA arthroplasty hospitals in the Netherlands, so individual surgeon data could be unblinded. All primary THAs implanted via DAA in these 6 centers between 2007 and 2019 were included (n = 15,903). Other approaches (posterolateral, anterolateral, DL), hip hemi-arthroplasties, hip resurfacing arthroplasties, metal-on-metal THA, and revision procedures were excluded.

Patient characteristics, procedure information, and implant details were retrieved from the register. Data from the LROI are matched with the national insurance database on healthcare (**22**), to obtain information on the vital status.

Learning curve

To assess the learning curve for the DAA, revision rates were calculated for the different phases of the learning curve. Within the 6 hospitals all procedures were ordered per surgeon, using the date of operation. Procedures were divided into 6 groups based on the number of previous procedures per surgeon (1–25, 26–50, 51–100, 101–150, 151–200, and > 200). Thereafter, data from different surgeons and hospitals was pooled; all THAs performed within the first 25 procedures per surgeon were pooled together. The other groups (26–50, 51–100, 101–150, 151–200, and > 200) were created similarly. Revision rates for the different groups were compared in order to assess the learning curve and survival rate of the DAA.

During the data exploration we noticed that in all centers there were surgeons with only a few procedures, which could possibly be the result of registration errors. Therefore, THAs performed by surgeons with < 10 procedures were excluded to increase the reliability of the data. Subsequently, the total number of procedures was 15,875.

Statistics

Survival time was calculated as the time from primary THA to first revision arthroplasty for any reason, death of the patient, or January 1, 2020 (end of follow-up). A revision arthroplasty is defined as any change (insertion, replacement, or removal) of 1 or more components. Standard survival analysis treats death simply as censored information but this approach overestimates revision rates (**23**). Therefore, the crude cumulative incidence of revision was calculated using competing risk analyses where death was considered to be a competing risk. Crude revision percentages within 5 and 9 years were estimated according to the different operation groups. Differences in revision rates were compared.

Furthermore, we had to take into account the nested structure of the dataset. Each patient belongs to 1 of the 6 hospitals. In theory, differences between patient outcomes could in fact be attributable to differences between the various hospitals. To correct for this random center effect and account for correlation among patients within hospitals, a 2-level frailty model was used. According to the hierarchical structure of the data, patients were defined as level 1, and hospitals as level 2, and a multilevel Cox regression analysis (time-to-event analysis) was performed (**24,25**). Specifically, a gamma frailty model with frailty effects for hospitals was fit (**26**). The model was adjusted for age, sex, ASA score, BMI, fixation type, and femoral head size. P-values below 0.05 were considered statistically significant. For the 95% confidence intervals (CI), we assumed that the number of observed cases followed a Poisson distribution. Data analysis was performed in an unblinded manner. Analyses were performed using SPSS 22.0 (IBM Corp, Armonk, NY, USA) and R statistics (R Foundation for Statistical Computing, Vienna, Austria.

Ethics, funding, and potential conflicts of interests

The study was approved by the board and scientific advisory committee of the LROI and the Medical Ethics Committee of the University Medical Center Groningen (no. METc 2021/280). The dataset was processed in compliance with the regulations of the LROI governing research on registry data. Data from the LROI cannot be shared due to data privacy policy regulations. No funding was received. No conflicting interests were declared.

Results

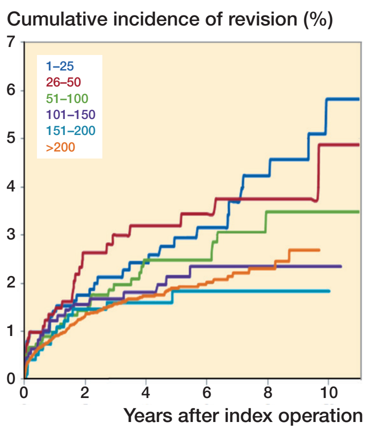
15,875 THAs were included in the analysis (Table 1, see Supplementary data). The mean follow up was 4.0 years (maximum 11.5 years). The THAs were performed by 43 different

Table 2. Number of surgeons per hospital and number of procedures per hospital per year

Hospital	No. of surgeons	No. of procedures	No. of procedures per hospital per year 2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	14	6,128	0	115	280	430	535	535	653	721	817	829	542	364	307
2	15	3,124	0	0	1	6	53	165	294	361	319	325	487	500	613
3	4	2,118	1	14	101	95	131	110	160	139	269	218	223	250	407
4	4	2,120	0	0	0	0	34	72	115	167	241	331	331	399	430
5	4	1,504	0	0	0	0	0	0	0	113	224	322	267	293	285
6	2	881	0	0	0	8	52	52	85	105	165	137	122	105	50
Total	43	15,875	1	129	382	539	805	934	1,307	1,606	2,035	2,162	1,972	1,911	2,092

Table 4. Crude cumulative incidence of revision for different operation groups for THA (non-case-mix corrected) (n = 15,875)

	Operation groups 1–25	26–50	51–100	101–150	151–200	>200
n (%)	1,024 (6.5)	827 (5.2)	1,390 (8.8)	1,111 (7.0)	1,005 (6.3)	10,518 (66.3)
Revision for any reason, % (CI)						
5-year	2.9 (2.0–4.4)	3.2 (2.1–4.8)	2.5 (1.7–3.6)	2.1 (1.4–3.3)	1.8 (1.1–3.1)	1.9 (1.6–2.2)
9-year	5.6 (3.1–6.7)	3.7 (2.5–5.6)	3.5 (2.3–5.2)	2.3 (1.5–3.6)	1.8 (1.1–3.1)	2.7 (2.1–3.5)



Cumulative incidence of revision according to operation group after primary THA using the direct anterior approach (n = 15,875).

Table 5. Reason for revision or reoperation in revised THAs performed in 2007–2020 in the Netherlands (n = 297). Values are count (%)

	Operation groups 1–25	26–50	51–100	101–150	151–200	>200	Total
Revised	33 (3.2)	26 (3.1)	33 (2.4)	21 (1.9)	15 (1.5)	169 (1.6)	297 (1.9)
Indication for revision [a]							
Loosening of stem	11	11	7	4	6	48 (28)	87 (29)
Infection	3	4	3	6	3	37 (22)	56 (19)
Dislocation	4	4	4	4	0	30 (18)	46 (16)
Periprosthetic fracture	5	4	4	6	2	20 (12)	41 (14)
Loosening of cup	3	4	4	1	3	15 (8.9)	30 (10)
Girdlestone	1	1	0	1	1	13 (7.7)	17 (5.7)
Cup/liner wear	0	0	1	0	0	5 (3.0)	6 (2.0)
Peri-articular ossification	0	0	2	0	0	2 (1.2)	4 (1.3)
Other	7	5	9	4	2	26 (15)	53(18)

[a] A patient may have more than 1 reason for revision or reoperation.

orthopedic surgeons across the 6 hospitals (respectively 14, 15, 4, 4, 4, and 2 per hospital). The number of procedures per hospital varied from 881 to 6,128 (Table 2). 43 different surgeons were included in the 1–25 procedure group, while 19 surgeons were present in the > 200 subgroup (Table 3, see Supplementary data).

Overall crude cumulative incidence of revision

297 THAs were revised (1.9%). The overall 5-year revision rate for all causes for the first 25 procedures per surgeon was 2.9% (CI 2.0–4.4) (if surgeons with < 10 cases are included as well, the 5-year revision rate rises to 3.4%). At 5 years, a lower cumulative incidence of revision was found when the surgeon had performed 151–200 (1.8%; CI 1.1–3.1) or more than 200 (1.9%; CI 1.6–2.2) previous DAA THAs. At 9 years, the crude revision rate was lower when the surgeon had performed 101–150 (2.3%; 1.5–3.6), 151–200 (1.8%; CI 1.1–3.1) or > 200 (2.7%; CI 2.1–3.5) THAs compared with first (1–25) and second 25 (26–50) cases (respectively 5.6%; CI 3.1–6.7 and 3.7%; CI 2.5–5.6) (Table 4, Figure). However, none of these differences were statistically significant.

Reason for revision

The most common reason for revision was loosening of the femoral component (29%), followed by periprosthetic infection (19%), dislocation (16%), and periprosthetic fracture

Table 6. Multivariable survival analysis of patients who underwent THA via the direct anterior approach between 2007 and 2020 in the 6 participating hospitals according to multilevel time-to-event analysis

Operation groups (procedures)	Hazard ratio (95% CI) [a]
1–25	1.6 (1.1–2.4) [b]
26–50	1.6 (1.1–2.5) [b]
51–100	1.3 (0.9–1.9)
101–150	1.0 (0.6–1.6)
151–200	0.8 (0. –1.4)
> 200	1.0 (reference)

[a] Adjusted for age, sex, ASA score, BMI, head size, fixation method, and hospital in which the operation was performed.
[b] $p < 0.05$.

(14%). In the early (< 25) phase of the learning curve, femoral loosening (33%) and periprosthetic fractures (15%) were the 2 most common revision causes; in the 100–200 phase, these were periprosthetic fracture (29%) and infection (29%), and in the final phase (> 200) femoral loosening (28%) and infection (22%). However, there were no statistically significant differences in reasons for revision between the groups (Table 5)

Overall adjusted multilevel analysis

Multivariable survival analysis demonstrated that patients in groups 1–25 and 26–50 had a higher risk of revision compared with patients in group > 200 (respectively HR 1.6; CI 1.1–2.4 and 1.6; CI 1.1–2.5). When orthopedic surgeons had performed more than 50 DAA THAs, the risk of revision was 26% higher (compared with > 200 group; HR 1.3; CI 0.9–1.9), albeit not statistically different. Above 100 procedures the hazard risk for revision further dropped to respectively 0.98 (CI 0.6–1.6) and 0.8 (CI 0.5–1.4) for patients in groups 101–150 and 151–200 (Table 6).

Furthermore, a statistically lower risk of revision was found for patients with a normal BMI (18.5–25) compared with patients with mild obesity (HR 0.7; CI 0.5–1.0), while severe obesity resulted in a 19% increased risk of revision (HR 1.2; CI 0.3–4.8). However, the latter was not statistically significant, perhaps due to low numbers (n = 94) (data not shown).

Lastly, small femoral head components (22–28 mm) resulted in an increased risk of revision compared with 32 mm heads (HR 1.6; CI 1.0–2.4). Reversed hybrid fixation technique (cemented cup with uncemented stem) also increased the risk of revision (HR 1.9; 1.1–3.1) compared with cementless fixation (data not shown).

Discussion

We found a 64% increased risk of revision for patients undergoing THA using the DAA for the first 50 cases per surgeon. Between 50 and 100 cases, this risk was around 30% increased, but not statistically different. From 100 cases onwards, a steady state had been reached in the revision rate. The learning curve for the DAA THA therefore is around 100 cases.

Previous literature

In general, the learning curve for surgical procedures can be defined as the number of times a task must be repeated before a steady state of outcome is reached (27).

During this learning curve, extra time, attention, and the support of an experienced surgeon may be needed to prevent early complications during this transition. After gaining experience, a reduction in operation time, perioperative blood loss, and a lower risk of complications were described (4). Our findings are in accordance with the literature. De Steiger et al. (14) found that 50 or more procedures should be performed by a surgeon before the rate of revision is not different from a surgeon performing 100 or more anterior THAs. That was based on results from 5,499 THAs registered in the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). A systematic review assessing the learning curve, safety, and accuracy of the DAA demonstrated a reduction in operation time and fluoroscopy time after the first 100 THAs (28). This was in accordance with findings of Nairn et al. (4). Their systematic literature review revealed a substantial learning curve for the DAA and a relative plateau in mean operation time after 100 cases.

Adequate positioning of THA components is important to reduce the risk of instability, component wear and impingement, resulting in dislocation or revision surgery (4). For surgeons switching from PL to DAA, changing from lateral decubitus into supine position could result in difficulties in regard to implant positioning during the early phases of the learning curve of the DAA (e.g., excessive acetabular anteversion or malpositioning of the stem). Kobayashi et al. (29) investigated implant positioning in the first 80 consecutive THA cases performed using the DAA with fluoroscopic assistance in comparison with their previous 80 THAs placed via the posterolateral approach. In the DAA group, the femoral component was more frequently positioned in flexion (than neutral) compared with the PL approach, although using fluoroscopy seemed to decrease the complications such as PFF during these first cases. Other studies described an increased risk of stem revision (for PFF or loosening) in patients operated on through the DAA compared with the posterolateral approach (16,30). A possible explanation is that surgical exposure of the femur is more complex with the DAA than with the PL approach. However, our data did not demonstrate an increased risk for femoral-sided complications during the first stages of the learning curve, possibly due to small numbers.

Case-mix and surgically modifiable factors

A high percentage of our patients were aged < 75 years (72%), female (68%), and had a low ASA score (I–II in 87%) and BMI (< 30 in 79%) compared with the total population of THA patients in the Netherlands (5). The adjusted analysis demonstrated a trend towards a lower risk of revision in patients with a normal BMI. This was consistent with previous findings in the general population (all approaches) where severe obesity and a high ASA score were identified as the strongest predictors for short-term revision after primary THA (31).

Therefore, it might be wise to take this into account during the first stages of the learning curve (e.g., perform the operation on patients with an acceptably low ASA without [severe] obesity).

As described, we included ASA score, BMI, fixation technique, age, and sex in our analysis as confounding variables since they might result in an increased risk for revision due to specific reasons. For example, there may be more revisions due to a PFF for uncemented THAs or more revisions due to a periprosthetic infection in patients with a high ASA score or severe obesity (31).

For the surgically modifiable factors, we found a higher risk of revision in patients with a small femoral head. This was in accordance with previous studies. Over the years (and thus learning curve), trends towards the use of larger femoral heads have resulted in improved survival rates. For example, a 60% increased risk of revision due to dislocation for small femoral heads (22–28 mm) compared to 32 mm femoral heads was demonstrated previously (9).

Overall, the most frequently used bearing type was metal-on-polyethylene (39%) with some variation across the groups. In the > 200 procedures subgroup, ceramic-on-polyethylene and ceramic-on-ceramic were relatively more frequently registered compared with the 0–25 subgroup (31–35% and 16–28% respectively) (Table 1, see Supplementary data). These findings are in line with the trend toward increased usage of larger femoral heads, cementless fixation, and advanced bearing surfaces over the past decade (9,32).

Limitations

There are some notable limitations to this study. Our data does not contain information on early postoperative complications that did not result in revision surgery such as dislocation and closed reduction, PFF in need of open reduction and internal fixation, or DAIR procedures without a component exchange. In addition, other perioperative parameters could not be monitored, e.g., duration of procedure, surgical instruments, component position, length of stay, opioid use or perioperative pain, occurrence of LFCN palsy, and intraoperative blood loss. Furthermore, the known limitations and risks of bias for observational studies are present for this study. Moreover, this data reflects the experience of 6 (high volume) hospitals, limiting the overall generalizability of the results. Nonetheless, the number of cases in these 6 ‘early adaptor’ centers make up 32% of the nationwide number of DAA THAs in the LROI. Furthermore, the surgical experience of the surgeon at the start of the learning curve is unknown. In our experience, there might be a difference between ‘first- and second-generation’ surgeons. Second-generation surgeons might have a shorter learning curve due to the fact that they have been taught about pearls and pitfalls by first-generation surgeons. In addition, it is not known if the operation was performed by an orthopedic surgeon or a resident. However, recent literature suggests that complication rates, revision percentages, and mortality rates are similar in THAs performed by a resident as primary surgeon compared with surgeries performed by an orthopedic surgeon (33).

Implications for further research

Future studies should focus on process assessment of learning curves when introducing new surgical approaches. Process assessment is supplementary to outcome assessment learning curve studies and has the benefit of needing a smaller sample size. This reduces the potential hazard to patients when introducing a new surgical technique. Given the low quality of previous studies, future studies should focus on learning curves and outcome relevant for patients, comparing new surgical techniques such as direct superior approach (34). In addition, future studies could focus on the learning curve of second-generation surgeons, who might have a shorter learning curve because they are supported by more experienced DAA surgeons (35). In our data, 43 different surgeons were encountered in the 1–25 group, while for the > 200 subgroup 19 surgeons were present. We could only speculate on the reason why surgeons may have “given up.” This could be for a multitude of reasons, e.g., simply because they have not reached the next phase of the learning curve at the time of data collection, or departure to another hospital (which might not be included in our data selection, e.g., private practice), or end of residency.

Implications for clinical practice

Patients and surgeons should discuss the need for shifting toward a new surgical approach given the risk a learning curve yields to patients. Given the lack of clear superior results of one surgical approach over the other for THA, and the increased risk (HR 1.6) of revision surgery (and hence complications) during the first 50 (to 100) patients when mastering the DAA, one should question the true need to switch surgical approach. Based on the latest LROI data, the all-cause survival rates of the DAA, posterolateral, direct lateral, and anterolateral approaches are all within 96–97% at 9-year follow-up, and the absolute differences in PROM improvement between approaches are only small (36). These data should be balanced against the increased risks to patients during the DAA learning curve. If a switch to DAA is chosen, some authors suggest this should be reserved for well-trained, high-volume surgeons and centers, perhaps avoiding very muscular and morbidly obese patients (37). Furthermore, when a switch in surgical approach is deliberated, one could consider training the DAA when in residency (35), following a dissection course, performing a number of procedures together with an experienced surgeon or the use of intraoperative fluoroscopy assistance. An appropriate amount of time should be planned, and the changes should be limited to the approach (in other words, do not simultaneously switch to a different prosthesis design as well). Lastly, the rest of the OR team (nurses, anesthesia staff) should be involved in the decision to change the approach.

In conclusion, using Dutch arthroplasty register data we found a clear learning curve for the DAA in THA. There was a significantly increased risk of revision for the first 50 cases per surgeon. Between 50 and 100 cases, the risk was still slightly elevated. From 100 cases onwards, a steady state had been reached. We therefore estimate the learning curve for direct anterior approach THA to be around 100 cases. Orthopedic surgeons can use these results in addition to the existing literature, when making decisions whether to use or to make the transition to the DAA.

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Authors contributed to (1) study design and study protocol, (2) gathered data, (3) analyzed data, (4) initial draft, and (5) final draft. RMP and WPZ contributed to 1–5; LvS contributed to 2, 3, and 5; HP contributed to 3, 4, and 5 KR; MR, CJV, BvS, RWP, SBWV, and BtH contributed to 1, 4, and 5.

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Supplementary data

Table 3. Number of surgeons per operation group, divided per hospital

	Operation groups					
	1–25	26–50	51–100	101–150	151–200	>200
Number of hospitals	6	6	6	6	6	6
Surgeons per hospital						
Hospital 1	14	10	10	7	7	6
Hospital 2	15	11	8	7	4	3
Hospital 3	4	4	3	2	2	2
Hospital 4	4	4	4	4	4	3
Hospital 5	4	4	4	3	3	3
Hospital 6	2	2	2	2	2	2
Total no. of surgeons	43	35	31	25	22	19

Table 1. Descriptive and clinical data on all patients who received a primary THA using the direct anterior approach in the period 2007–2020 in the 6 participating hospitals (n = 15,875). Values are count (%) and do not add up to total due to unknown or missing values. Smoking, Charnley score, and BMI registered since 2014.

	Operation groups						
	1–25	26–50	51–100	101–150	151–200	>200	Total
n (%)	1,024 (6.5)	827 (5.2)	1,390 (8.8)	1,111 (7.0)	1,005 (6.3)	10,518 (66.3)	15,875
Age [b]							
< 60	164 (16)	134 (16)	232 (17)	189 (17)	161 (16)	1,984 (19)	2,864 (18)
60–74	554 (54)	463 (56)	744 (54)	608 (55)	520 (52)	5,627 (54)	8,516 (54)
≥ 75	304 (30)	230 (28)	414 (30)	313 (28)	323 (32)	2,907 (28)	4,491 (28)
Sex							
Male	344 (34)	260 (31)	460 (33)	373 (34)	311 (31)	3,569 (34)	5,317 (34)
Female	674 (66)	566 (69)	930 (67)	736 (66)	694 (69)	6,947 (66)	10,547 (66)
ASA score [b]							
I	248 (25)	192 (24)	313 (23)	283 (26)	257 (26)	2,636 (25)	3,929 (25)
II	591 (60)	519 (65)	847 (62)	656 (60)	571 (58)	6,418 (62)	9,602 (62)
III–IV	144 (15)	83(11)	197 (15)	153 (14)	155 (16)	1,356 (13)	2,088 (13)
Diagnosis							
OA	947 (94)	762 (93)	1,287 (93)	1,034 (94)	921 (92)	9,740 (93)	14,691 (93)
Non-OA	60 (6.0)	58 (7.1)	98 (7.1)	67 (6.1)	76 (7.6)	744 (7.1)	1,103 (7.0)
Previous operation [a]							
Yes	12 (1.2)	12 (1.5)	28 (2.0)	27 (2.5)	24 (2.5)	241 (2.3)	344 (2.2)
No	1,002 (98)	807 (99)	1,351 (98)	1,072 (98)	935 (98)	10,142 (98)	15,309 (98)
Smoking status							
Yes	67 (10)	54 (11)	125 (14)	83 (12)	92 (12)	961 (11)	1,382 (11)
No	584 (90)	441 (89)	741 (86)	635 (88)	666 (88)	7,689 (89)	10,756 (89)
BMI							
≤ 18.5	5 (0.8)	2 (0.4)	6 (0.7)	1 (0.1)	9 (1.2)	72 (0.8)	95 (0.8)
> 18.5–25	211 (33)	189 (38)	312 (36)	244 (34)	262 (34)	3,127 (36)	4,345 (36)
> 25–30	287 (45)	225 (45)	373 (44)	317 (44)	337 (44)	3,713 (42)	5,252 (43)
> 30–40	130 (20)	81 (16)	160 (19)	146 (20)	162 (21)	1,769 (20)	2,448 (20)
> 40	3 (0.5)	1 (0.2)	6 (0.7)	9 (1.3)	3 (0.4)	72 (0.8)	94 (0.8)
Charnley score [a]							
A	286 (47)	224 (47)	375 (47)	301 (44)	276 (41)	3,370 (41)	4,832 (42)
B1	211 (34)	170 (36)	267 (33)	256 (38)	239 (36)	2,680 (33)	3,823 (34)
B2	104 (17)	79 (17)	147 (18)	113 (17)	148 (22)	1,941 (24)	2,532 (22)
C	13 (2.1)	6 (1.3)	11 (1.4)	10 (1.5)	7 (1.0)	187 (2.3)	234 (2.0)
ODEP rating stem							
< 5A	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	6 (0.1)	6 (0.0)
≥ 5A	1,012 (99)	819 (99)	1,380 (99)	1,100 (99)	996 (99)	10,459 (99)	15,766 (99)
Unknown	12 (1.2)	8 (1.0)	10 (0.7)	11 (1.0)	9 (0.9)	53 (0.5)	103 (0.6)
ODEP rating cup [a]							
< 5A	2 (0.2)	1 (0.1)	1 (0.1)	1 (0.1)	0 (0.0)	663 (6.3)	668 (4.2)
≥ 5A	1,018 (99)	825 (100)	1,389 (100)	1,110 (100)	1,001 (100)	9,820 (93)	15,163 (96)
Unknown	4 (0.4)	1 (0.1)	0 (0.0)	0 (0.0)	4 (0.4)	35 (0.3)	44 (0.3)
Configuration stem [a]							
Anatomic	683 (67)	558 (68)	954 (69)	823 (74)	774 (77)	8,212 (78)	12,004 (76)
Shoulder	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.0)
Other [c]	341 (33)	268 (32)	436 (31)	288 (26)	231 (23)	2,306 (22)	3,870 (24)
Head size, mm [a]							
22–28	422 (41)	320 (39)	458 (33)	349 (31)	267 (27)	2,276 (22)	4,092 (26)
32	366 (36)	297 (36)	595 (43)	462 (42)	456 (45)	4,789 (46)	6,965 (44)
36	236 (23)	210 (25)	334 (24)	300 (27)	282 (28)	3,452 (33)	4,814 (30)
≥ 38	0 (0.0)	0 (0.0)	3 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	3 (0.0)
Fixation [a]							
Cemented	305 (30)	242 (29)	397 (29)	263 (24)	210 (21)	1,959 (19)	3,376 (21)
Cementless	531 (52)	470 (57)	788 (57)	700 (63)	663 (66)	7,390 (70)	10,542 (67)
Reversed hybrid	167 (16)	107 (13)	180 (13)	138 (12)	121 (12)	985 (9.4)	1,698 (11)
Hybrid	11 (1.1)	3 (0.4)	16 (1.2)	6 (0.5)	9 (0.9)	119 (1.1)	164 (1.0)
Unknown	3 (0.3)	3 (0.4)	4 (0.3)	3 (0.3)	2 (0.2)	43 (0.4)	58 (0.4)
Bearing type [a]							
Metal-on-PE	541 (53)	388 (47)	623 (45)	467 (42)	411 (41)	3,786 (36)	6,216 (39)
Cer-on-PE	314 (31)	290 (35)	518 (37)	437 (39)	389 (39)	3,636 (35)	5,584 (35)
Cer-on-cer	168 (16)	137 (17)	241 (17)	203 (18)	204 (20)	2,961 (28)	3,914 (25)
OxZ-on-PE	0 (0.0)	12 (1.5)	7 (0.5)	2 (0.2)	1 (0.1)	135 (1.3)	157 (1.0)
Cer-on-metal	1 (0.1)	0 (0.0)	0 (0.0)	2 (0.2)	0 (0.0)	0 (0.0)	3 (0.0)
Period							
2007–2011	310 (30)	228 (28)	231 (17)	145 (13)	144 (14)	798 (7.6)	1,856 (12)
2012–2015	306 (30)	249 (30)	514 (37)	489 (44)	454 (45)	3,870 (37)	5,882 (37)
2016–2019	408 (40)	350 (42)	645 (46)	477 (43)	407 (41)	5,850 (56)	8,137 (51)

[a] $p < 0.0001$, [b] $p < 0.05$. [c] Missing or cemented.
OA: osteoarthritis, ODEP: Orthopaedic Data Evaluation Panel, PE: polyethylene. Cer: ceramic.
OxZ: oxidized zirconium/oxinium.