Osteoarthritis and Cartilage xxx (2015) 1–8

Osteoarthritis and Cartilage

OARSI OSTEOARTHRITIS RESEARCH SOCIETY INTERNATIONAL

Association between hospital procedure volume and risk of revision after total hip arthroplasty: a population-based study within the Nordic Arthroplasty Register Association database

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ARTICLE INFO

Article history:
Received 4 February 2015
Accepted 21 September 2015

Keywords:
Total hip arthroplasty
Osteoarthritis
Hospital volume
Adverse event
Joint revision

SUMMARY

Objective: Outcome after total hip arthroplasty (THA) depends on several factors related to the patient, the surgeon and the implant. It has been suggested that the annual number of procedures per hospital affects the prognosis. We aimed to examine if hospital procedure volume was associated with the risk of revision after primary THA in the Nordic countries from 1995 to 2011.

Design: The Nordic Arthroplasty Register Association database provided information about primary THA, revision and annual hospital volume. Hospitals were divided into five volume groups (1–50, 51–100, 101–200, 201–300, >300). The outcome of interest was risk of revision 1, 2, 5, 10 and 15 years after primary THA. Multivariable regression was used to assess the relative risk (RR) of revision.

Results: 417,687 THAs were included. For the 263,176 cemented THAs no differences were seen 1 year after primary procedure. At 2, 5, 10 and 15 years the four largest hospital volume groups had a reduced risk of revision compared to group 1–50. After 10 years RR was for volume group 51–100 0.79 (CI 0.65–0.95), group 101–200 0.76 (CI 0.61–0.95), group 201–300 0.74 (CI 0.57–0.96) and group >300 0.57 (CI 0.46–0.71). For the uncemented THAs an association between hospital volume and risk of revision were only present for hospitals producing 201–300 THAs per year, beginning at years 2 through 5 and in all subsequent time intervals to 15 years.

Conclusion: Hospital procedure volume was associated with a long term risk of revision after primary cemented THA. Hospitals operating 50 procedures or less per year had an increased risk of revision after 2, 5, 10 and 15 years follow up.

Introduction

The incidence of THA is increasing[1]. Although THA is considered to be a safe and successful procedure still about 5–10% of patients are revised or sustain complications within the first 10 years after primary THA[2].

A number of patient, implant and surgery related factors have previously been identified as risk factors for revision surgery following primary THA[3–11]. During the last decade health care

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http://dx.doi.org/10.1016/j.joca.2015.09.014
1063-4584/

Please cite this article in press as: Glassou EN, et al., Association between hospital procedure volume and risk of revision after total hip arthroplasty: a population-based study within the Nordic Arthroplasty Register Association database, Osteoarthritis and Cartilage (2015), http://dx.doi.org/10.1016/j.joca.2015.09.014

provider related factors such as annual surgeon and hospital THA volume have been increasingly in focus leaving the impression that larger hospital volumes decrease the risk of various adverse events[12–22]. In a recent register-based study Singh *et al.* demonstrated positive relationship between larger hospital procedure volume and lower rate of 1-year mortality for both hip and knee arthroplasty[21]. A similar association between hospital THA volume and 90 days mortality after THA has been shown by Soohoo *et al.*[22] The occurrence of other short-term adverse events after THA such as readmission, dislocations, thromboembolic events, infections and even short-term risk of revision have been shown to be associated with procedure volume[17,19,21,22]. Only a few studies examined the association between hospital procedure volume and long term risk of revision, and none of them found such an association[14,18,20,23]. Even though these four studies are large, population-based and with follow-up times between 1 and 12 years, different geographical settings and healthcare systems impede the generalizability of their results.

The aim of our study was to investigate the association between hospital procedure volume and risk of implant revision surgery after primary THA in patients suffering from osteoarthritis (OA) in the Nordic countries from 1995 to 2011 using the Nordic Arthroplasty Register Association database (NARA). The investigation included revision due to all causes, specific causes and in relation to fixation type.

Patients and methods

Data sources

The NARA database was established in 2007. It holds merged individual-based data concerning diagnosis, primary surgery, type of implant and revision from the Danish, Finnish, Norwegian and Swedish hip and knee arthroplasty registers[24,25]. On a regular basis all uniform variables from each national register are re-coded according to common definitions and anonymized and then merged into the NARA database. The linkage between primary procedure and subsequent revision or death on individual data is performed in each national register before merged into the NARA database. Each of the four national registers holds data from both public and private hospitals.

Study population

All primary THAs due to primary OA between 1st January 1995 and 31st of December 2011 were included. Hip resurfacing arthroplasties were excluded while other metal on metal THAs were included. Bilateral THAs were included. No age restriction was made. THAs with missing information on primary hospital were excluded ($n = 5$). In total 417,687 primary THAs were included in this study. The characteristics of the study population according to hospital volume groups are presented in Table I.

Exposure – hospital volume

Each procedure was entered into one of five hospital THA volume groups according to the number of primary THAs due to primary OA at the hospital in the year of the procedure. The volume groups were 1–50, 51–100, 101–200, 201–300 and >300 primary THAs per year. Hospitals with fluctuating procedure volume contributed to more than one volume group. Thus, a hospital performing 188 procedures in 2010 and 204 in 2011 contribute to volume group 101–200 in 2010 and to volume group 201–300 in 2011.

Outcome – revision

The primary outcome of interest was first time implant revision from all causes. Revision was defined as any new surgical procedure including both partial and complete change and/or removal of a primary implant. Each primary THA was linked to the following first time revision, if present, using the patients civil personal registration number. Follow-up started on the day of primary surgery and ended on day of revision, patient death with the implant *in situ* or December 31st, 2011 whichever came first.

Statistical analysis

The descriptive statistics included median age at primary THA, sex and type of fixation. For the primary outcome of interest cumulative incidence estimation in the presence of death as a competing risk was calculated and visualized graphically. The Pseudo Value Approach[26–28] taking death as a competing risk into account was used to assess the relative risk (RR) of revision from all causes 1, 2, 5, 10 and 15 years after primary surgery. We adjusted for the following confounding factors; age at primary procedure (in categories 10–49, 50–59, 60–69, 70–79 and 80+ years) and sex. Type of fixation was – using both the Wald Test and the Likelihood Ratio Test at 10 years follow up on revision from all causes – tested to be an effect modifier (for both tests $P < 0.00$). Therefore, analyses were made on cemented THA and uncemented THA separately. Hybrids were, to keep it simple, omitted when looking at association between hospital volume and risk of revision in relation to type of fixation. Sensitivity analysis using the same statistical approach was made on first time implant revision from specific causes (aseptic loosening, dislocation and deep infection) 2 and 10 years after primary surgery. In all analyses, the group with the lowest primary THA volume (annual volume of 1–50 THAs) acted as the reference group. Due to both the age of the patient at primary surgery and the long expected survival of the implant death is to be considered as a competing risk to revision[29,30]. By doing so we avoid overestimating the risk of revision as would be the case with standard survival analysis. A possible correlation among patients treated in the same hospital (case mix related to hospitals) is dealt with by correcting for clustering using robust estimates of the variance. Risk estimates were presented with 95% CI and *P*-values relative to volume group 1–50. For the sensitivity analyses only adjusted RR was presented. *P*-values <0.05 were taken to donate statistical significance.

The analyses were performed using the Stata Statistical Software; Release 12.0, StataCorp LP.

Ethics

Permission to the study was obtained from the Danish Data Protection Agency (reference number: 2012-41-06636). As both individuals and hospitals were anonymized before entering the NARA database, it was not possible to identify both on an individual basis in the NARA database.

Results

The annual number of THAs increased almost two-fold from 16,501 in 1995 to 31,328 in 2011 (Fig. 1). During the period from 1995 to 2011 the annual number of primary THAs increased in the three largest volume groups – most pronouncedly in the largest annual hospital volume group (volume of >300 THAs), whereas the annual number of primary THAs in the two smallest hospital volume groups decreased. Number of THAs at risk for revision was

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Table I
Number of procedures, study population characteristics and number of hospitals according to hospital volume groups and in total

	Hospital volume groups					In total
	1–50	51–100	101–200	201–300	>300	
No. of THAs (%)	36,198 (9)	103,589 (25)	156,464 (37)	60,084 (14)	61,352 (15)	417,687
No. of THAs at 1 year	33,937	97,283	142,249	51,581	51,325	376,375
No. of THAs at 2 years	31.872	90,951	128,616	45,386	41,041	337,866
No. of THAs at 5 years	24,177	70,809	90,406	28,389	17,859	231,640
No. of THAs at 10 years	11,724	33,601	33,972	8,584	2,434	90,315
No. of THAs at 15 year	2,177	5,966	5,540	484	281	14,448
No. of revisions (%)	2,407 (12)	6,050 (31)	7,173 (36)	2,385 (12)	1,719 (9)	19,734
Follow-up time in years (IQR)	7.5 (7.3)	7.4 (7.1)	6.1 (6.6)	4.7 (5.8)	3.0 (3.9)	5.7 (6.7)
Female %	61	60	59	59	60	59
Age at primary surgery (IQR)	71 (13)	70 (13)	70 (13)	70 (13)	69 (14)	70 (13)
Age group 10–49 %	2.6	2.7	3.2	2.7	3.3	3.0
Age group 50–59 %	11.9	13.1	13.5	13.3	13.3	13.2
Age group 60–69 %	31.0	31.3	32.1	33.7	34.1	32.3
Age group 70–79 %	40.1	39.0	37.4	36.6	35.7	37.7
Age group 80+ %	14.4	13.9	13.8	13.8	13.7	13.9
No. of cemented THAs (%)	23,320 (65)	68,819 (67)	104,867 (67)	34,501 (58)	31,669 (52)	263,176 (63)
No. of uncemented THAs (%)	7,883 (22)	21,379 (21)	31,839 (20)	15,899 (26)	20,534 (34)	97,534 (24)
No. of hybrid THAs (%)	4,802 (13)	13,031 (13)	19,257 (13)	9,606 (16)	8,806 (14)	55,502 (13)
No. of hospitals 1995–2011*	179	153	124	56	33	342
No. of hospitals in 1995	116	93	43	2	1	255
No. of hospitals in 2011	67	47	75	28	18	235

* Hospitals with fluctuating procedure volume can contribute to more than one volume group.

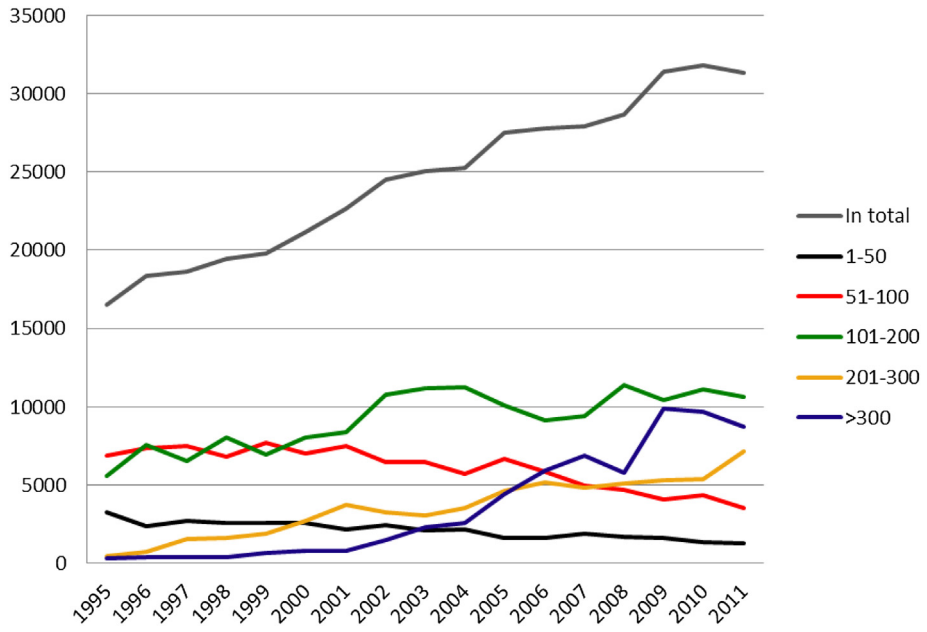

Fig. 1. Annual number of total hip arthroplasties, overall and according to hospital volume groups.

largest in hospital volume group 50–100 and hospital volume group 101–200 at all time points (Table I). Number of THAs at risk in the two largest hospital volume group (volumes of 200–300 and >300 THAs) were limited 10 and 15 years after primary procedure (Table I). The number of hospitals performing 100 or less primary THAs per year decreased from 1995 to 2011. At the same time the number of hospitals operating more than 101 primary THAs per year increased (Table I).

The median follow-up time was 5.7 years ranging from 0 to 17 years (Table I). The longest median follow-up time at 7.5 years was seen for hospital volume group 1–50. The follow-up time decreased gradually with increase in hospital volume group resulting in a follow-up time of median 3.0 years in volume group >300.

Revision from any cause

In total, 19.734 (4.7%) first time implant revisions were performed over the study period. The overall cumulative incidence of revision was 1.4% (CI 1.3–1.5) 1 year after primary THA. At 2 years, it had increased to 1.8% (CI 1.7–1.9), at 5 years to 2.9% (CI 2.8–3.0), at 10 years to 5.9% (CI 5.7–6.1) and at 15 years the overall cumulative incidence of revision was 9.2% (CI 8.9–9.4). Cumulative incidences for each volume group can be seen in Fig. 2.

Revision from all causes – cemented THA

There were in total 263,176 (63%) cemented THAs (Table III). No differences were found in the adjusted RR between any of the

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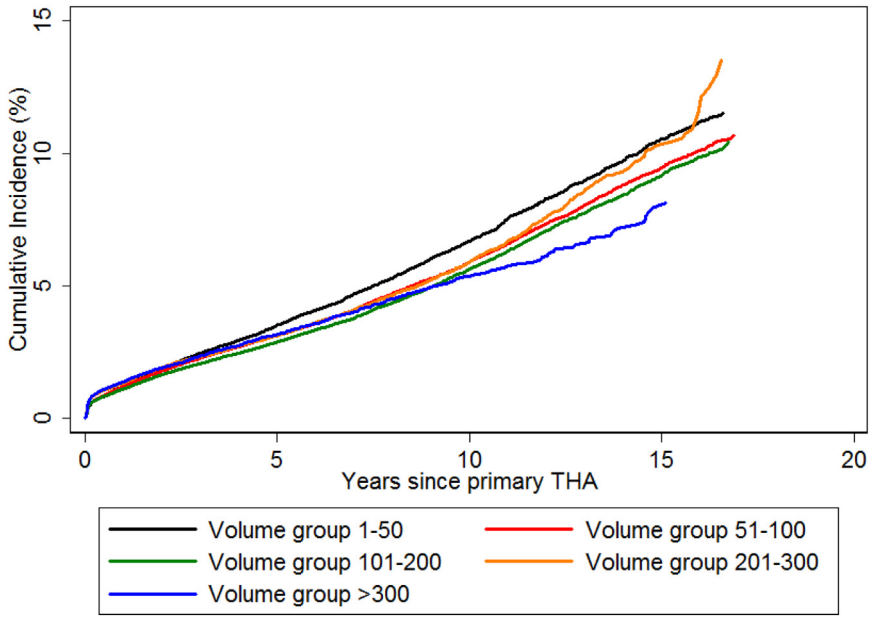

Fig. 2. Cumulative incidence of revisions following 417,687 primary total hip arthroplasties according to hospital volume groups.

hospital volume groups 1 year after primary THA (Table II). At 2, 5 and 10 years all hospital volume groups had a reduced RR compared to the reference group (annual volume of 1–50 THAs) (Table II). At 15 years all but hospital volume group 201–300 had a reduced RR compared to the reference group. The specific periods in which volume is most important were 2–5 years and 5–10 years after primary procedure. Here the reduction of adjusted RR of revision varied between 21% and 43% in the four largest volume groups compared to the reference group. For hospital volume group >300 the magnitude of RR reduction grew with increased follow up (Table II).

Revision from all causes – uncemented THA

There were 97,534 (23%) uncemented THAs. At 1 and 2 years, no differences in RR were seen (Table III). At 5, 10 and 15 years, solely

Table II
Number of revisions after cemented total hip arthroplasty (THA) from all causes and RR of revision with 95% confidence interval (CI) according to hospital volume groups 1, 2, 5, 10 and 15 years after primary THA. The RR estimates are adjusted for age and sex

Hospital volume groups	No. of revisions performed within the period (%)	Crude RR (CI)	*P*-value	Adjusted RR (CI)	*P*-value
0–1 year after primary THA					
1–50	224 (0.96)	1 (reference)		1 (reference)	
51–100	640 (0.93)	0.97 (0.81–1.15)	0.71	0.93 (0.77–1.11)	0.42
101–200	825 (0.79)	0.82 (0.67–1.01)	0.06	0.79 (0.64–0.98)	0.03
201–300	304 (0.88)	0.93 (0.71–1.21)	0.58	0.90 (0.69–1.18)	0.46
>300	326 (1.03)	1.09 (0.87–1.38)	0.45	1.05 (0.84–1.32)	0.67
1–2 years after primary THA					
1–50	115 (0.66)	1 (reference)		1 (reference)	
51–100	331 (0.48)	0.72 (0.58–0.89)	0.00	0.72 (0.58–0.90)	0.00
101–200	446 (0.43)	0.66 (0.52–0.83)	0.00	0.64 (0.50–0.82)	0.00
201–300	163 (0.47)	0.76 (0.58–1.00)	0.05	0.74 (0.56–0.98)	0.03
>300	115 (0.36)	0.63 (0.47–0.84)	0.00	0.63 (0.45–0.88)	0.01
2–5 years after primary THA					
1–50	323 (1.39)	1 (reference)		1 (reference)	
51–100	729 (0.06)	0.75 (0.62–0.90)	0.00	0.72 (0.59–0.87)	0.00
101–200	973 (0.93)	0.71 (0.58–0.87)	0.00	0.68 (0.55–0.83)	0.00
201–300	285 (0.83)	0.69 (0.54–0.87)	0.00	0.66 (0.52–0.85)	0.00
>300	183 (0.58)	0.62 (0.49–0.79)	0.00	0.61 (0.46–0.81)	0.00
5–10 years after primary THA					
1–50	461 (1.98)	1 (reference)		1 (reference)	
51–100	1,132 (1.64)	0.83 (0.69–0.99)	0.04	0.79 (0.65–0.95)	0.01
101–200	1,449 (1.38)	0.83 (0.67–1.04)	0.10	0.76 (0.61–0.95)	0.02
201–300	366 (1.06)	0.86 (0.67–1.10)	0.23	0.74 (0.57–0.96)	0.02
>300	131 (0.41)	0.69 (0.55–0.87)	0.00	0.57 (0.46–0.71)	0.00
10–15 years after primary THA					
1–50	266 (1.14)	1 (reference)		1 (reference)	
51–100	666 (0.97)	0.83 (0.67–1.04)	0.10	0.75 (0.60–0.95)	0.02
101–200	714 (0.68)	0.86 (0.68–1.08)	0.20	0.74 (0.58–0.96)	0.02
201–300	153 (0.44)	1.08 (0.80–1.48)	0.63	0.85 (0.60–1.22)	0.38
>300	30 (0.09)	0.55 (0.44–0.69)	0.00	0.43 (0.34–0.54)	0.00

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Table III
Number of revisions after uncemented THA from all causes and RR of revision with 95% confidence interval (CI) according to hospital volume groups 1, 2, 5, 10 and 15 years after primary THA. The RR estimates are adjusted for age and sex

Hospital volume groups	No. of revisions performed within the period (%)	Crude RR (CI)	*P*-value	Adjusted RR (CI)	*P*-value
0–1 year after primary THA					
1–50	151 (1.92)	1 (reference)		1 (reference)	
51–100	397 (1.86)	0.97 (0.77–1.22)	0.77	0.95 (0.75–1.20)	0.65
101–200	612 (1.92)	1.01 (0.79–1.28)	0.95	1.00 (0.77–1.28)	0.97
201–300	331 (2.08)	1.11 (0.82–1.50)	0.50	1.11 (0.82–1.49)	0.50
>300	361 (1.76)	0.94 (0.74–1.20)	0.62	0.92 (0.72–1.18)	0.51
1–2 years after primary THA					
1–50	42 (0.53)	1 (reference)		1 (reference)	
51–100	164 (0.77)	1,46 (1.01–2.13)	0.05	1.41 (0.98–2.05)	0.07
101–200	211 (0.66)	1.37 (0.96–1.97)	0.08	1.36 (0.95–1.95)	0.09
201–300	85 (0.53)	1.26 (0.83–1.93)	0.28	1.23 (0.80–1.87)	0.35
>300	102 (0.50)	1.22 (0.83–1.80)	0.31	1.22 (0.83–1.80)	0.31
2–5 years after primary THA					
1–50	97 (1.23)	1 (reference)		1 (reference)	
51–100	263 (1.23)	0.99 (0.75–1.30)	0.92	0.96 (0.72–1.28)	0.79
101–200	269 (0.84)	0.84 (0.65–1.10)	0.21	0.82 (0.62–1.09)	0.17
201–300	89 (0.56)	0.72 (0.52–1.00)	0.05	0.71 (0.51–0.99)	0.04
>300	137 (0.67)	1.11 (0.67–1.87)	0.68	1.11 (0.65–1.92)	0.70
5–10 years after primary THA					
1–50	165 (2.09)	1 (reference)		1 (reference)	
51–100	369 (1.73)	0.84 (0.60–1.16)	0.29	0.82 (0.59–1.15)	0.26
101–200	283 (0.89)	0.79 (0.56–1.11)	0.17	0.77 (0.54–1.09)	0.14
201–300	69 (0.43)	0.63 (0.41–0.96)	0.03	0.59 (0.38–0.93)	0.02
>300	42 (0.20)	0.94 (0.64–1.40)	0.78	0.87 (0.56–1.35)	0.53
10–15 years after primary THA					
1–50	131 (1.66)	1 (reference)		1 (reference)	
51–100	283 (1.32)	0.82 (0.59–1.10)	0.17	0.74 (0.57–1.02)	0.06
101–200	182 (0.57)	0.77 (0.54–1.08)	0.13	0.71 (0.50–1.01)	0.06
201–300	28 (0.18)	0.69 (0.46–1.04)	0.08	0.62 (0.40–0.95)	0.03
>300	11 (0.05)	2.14 (1.01–4.52)	0.05	1.70 (0.75–3.89)	0.21

hospitals producing between 201 and 300 procedures per year had a reduced RR of revision compared to the reference group. For hospital volume group 50–100, 101–300 and >300 no differences were found in the adjusted RR compared to the reference group (Table III).

Revision due to specific causes

The main reason for implant revision was aseptic loosening. It accounted for 49% of all the revisions, 56% in the cemented THAs and 32% in the uncemented THAs. For both the cemented THAs and uncemented THAs the share of revisions due to aseptic loosening decreased with increasing hospital volume. For the cemented THAs all the four largest hospital volume groups had a reduced RR compared to the reference group (annual volume of 1–50 THAs) both 2 and 10 years after primary THA. For the uncemented THAs no differences were found in the adjusted RR compared to the reference group neither 2 nor 10 years after primary THA (see Table IV).

Dislocation accounted for 20% of all the revisions. There were no differences in RR between the reference group and the larger hospital volume groups after 2 years follow up. After 10 years follow up hospital volume group 101–200 had a reduced risk of revision compared to the reference group (Table V). Deep infections accounted for 13% of the revisions. There were no differences in RR due to deep infection between the reference group and the larger volume groups neither 2 nor 10 years after primary THA (Table V). Due to low numbers of primary THAs and even smaller numbers of revisions in the compared hospital volume groups we were not able to estimate risk of revision due to dislocation and infection for the cemented THAs and the uncemented THAs.

Table IV
Number of revisions due to aseptic loosening and RR of revision with 95% confidence interval (CI) according to hospital volume groups 2 and 10 years after cemented primary THA and uncemented primary THA. The RR estimates are adjusted for age and sex

Hospital volume groups	No. of revisions due to aseptic loosening within the period (%)	Adjusted RR (CI)	*P*-value	No. of revisions due to aseptic loosening within the period (%)	Adjusted RR (CI)	*P*-value
Cemented THA	0–2 years after primary THA			2–10 years after primary THA		
1–50	114 (0.49)	1 (reference)		565 (2.42)	1 (reference)	
51–100	211 (0.32)	0.61 (0.47–0.80)	0.00	1,326 (1.93)	0.76 (0.62–0.93)	0.01
101–200	249 (0.24)	0.47 (0.34–0.65)	0.00	1,665 (1.59)	0.69 (0.55–0.87)	0.00
201–300	78 (0.23)	0.48 (0.34–0.69)	0.00	410 (1.19)	0.63 (0.47–0.83)	0.00
>300	53 (0.17)	0.37 (0.21–0.65)	0.00	157 (0.50)	0.49 (0.38–0.63)	0.00
Uncemented THA	0–2 years after primary THA			2–10 years after primary THA		
1–50	39 (0.49)	1 (reference)		97 (1.23)	1 (reference)	
51–100	121 (0.57)	1.18 (0.70–1.98)	0.54	249 (1.15)	0.90 (0.50–1.61)	0.72
101–200	157 (0.49)	1.04 (0.62–1.72)	0.89	222 (0.70)	0.94 (0.54–1.61)	0.81
201–300	68 (0.43)	1.00 (0.57–1.76)	1.00	58 (0.36)	0.66 (0.30–1.45)	0.30
>300	139 (0.68)	1.50 (0.73–3.06)	0.27	112 (0.55)	1.31 (0.66–2.60)	0.45

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Table V
Number of revisions due to dislocation and deep infection and RR of revision with 95% confidence interval (CI) according to hospital volume groups 2 and 10 years after primary THA. The RR estimates are adjusted for age and sex

Hospital volume groups	No. of revisions due to specific cause within the period (%)	Adjusted RR (CI)	*P*-value	No. of revisions due to specific cause within the period (%)	Adjusted RR (CI)	*P*-value
Dislocation	0–2 years after primary THA			2–10 years after primary THA		
1–50	203 (0.56)	1 (reference)		193 (0.53)	1 (reference)	
51–100	604 (0.58)	1.02 (0.82–1.27)	0.85	452 (0.44)	0.79 (0.59–1.05)	0.10
101–200	819 (0.52)	0.94 (0.75–1.16)	0.55	510 (0.33)	0.70 (0.54–0.90)	0.01
201–300	366 (0.61)	1.13 (0.86–1.50)	0.38	218 (0.36)	0.96 (0.65–1.41)	0.84
>300	279 (0.45)	0.88 (0.62–1.25)	0.46	127 (0.21)	0.84 (0.62–1.14)	0.26
Deep infection	0–2 years after primary THA			2–10 years after primary THA		
1–50	142 (0.39)	1 (reference)		72 (0.20)	1 (reference)	
51–100	454 (0.44)	1.07 (0.84–1.35)	0.56	198 (0.19)	0.83 (0.57–1.22)	0.34
101–200	669 (0.43)	1.04 (0.80–1.34)	0.77	293 (0.19)	0.98 (0.68–1.40)	0.90
201–300	311 (0.52)	1.30 (0.95–1.78)	0.10	86 (0.14)	0.90 (0.59–1.36)	0.61
>300	284 (0.46)	1.14 (0.86–1.51)	0.35	51 (0.08)	0.74 (0.49–1.10)	0.14

Discussion

For cemented THA we found a consistent association between annual hospital THA volume and long term risk of implant revision. To be more specific, a mean annual hospital THA volume of 50 THAs or less per year increased the risk of revision after 2, 5, 10 and 15 years after primary cemented THA in patients operated on for primary OA. To the best of our knowledge, this is the largest study to evaluate presence of any association between hospital procedure volume and risk of revision.

We acknowledge some limitations in our study. First, registration of primary THA and revisions in the national hip registers is not 100%, but close[31–33]. Although we may miss some revisions due to prospective registration of data, we have no reason to believe that missing revisions are related to certain hospital volume groups. Second, we used hospital procedure volume as the exposure. A relevant alternative would be surgeon procedure volume. Ravi *et al.* showed recently that adverse events after THA were increased in patients treated by surgeons performing less than 35 procedures per year[34]. Additionally Katz *et al.* showed that the risk of revision after THA was increased for low volume surgeons in the first 18 month after primary THA[23]. We do not have information about surgeon procedure volume in the NARA database and since it is not possible to extrapolate our hospital volume to surgeon volume residual confounding may influence our estimations. Finally, the main outcome in our study was revision surgery. In order to improve our understanding of the long-term clinical course of patients undergoing THA surgery it would be preferable to also examine other clinical adverse events and patient reported outcomes following THA. Unfortunately, these data were not available in the NARA database. Another issue that might play a role in the interpretation of our results is the fact that small volume hospitals represent a larger share of the total amount of THAs in the early study period compared to the more recent study period where large volume hospitals are over-represented. So, provided that older implants are of poor quality and newer implants are of better quality, one can argue that our findings of a positive long term association between hospital volume and risk of revision are more related to implant quality than to hospital volume. However, this premise of old/new implants being of more inferior/superior quality can be questioned. Additionally, data from the national registers from Sweden and Denmark which constitute parts of the NARA database do not unambiguous support a premise like this[31,33].

We had a priory chosen five hospital volume groups with fixed cut points. Our hospital volume groups correspond very much to those used by Judge *et al.*[14] The smaller hospital volume groups were identical while the large volume groups in their study used larger cut point therefore reflecting demographic differences between England and the Nordic countries. As different grouping might give rise to different results we casted a sidelong glance to other studies in the preparation of the present study. However, the variety in hospital volume groups is large and impedes a direct comparison between studies. On the other hand, a consensus seems difficult because of differences in national heterogeneities and study designs.

Four different register studies using similar methods compared to us did not find any association between hospital procedure volume and short or long term risk of revision after THA[14,18,20,23]. In the largest of these studies, the study by Judge *et al.* based on 281.000 patients from England, the authors found no evidence that volume was associated with risk of revision within 5 years of primary surgery[14]. The same result was found in 31,000 patients from Canada 1 year after primary surgery[20]. In more than 25,000 Medicare patients in USA Manley *et al.* found no association between hospital procedure volume and revision 6 month, 2, 5 and 8 years after primary procedure[18]. Same result was found by Katz *et al.* in a more recent and larger study based on Medicare patients in USA[23]. Here the authors didn't find justification for hospital procedure volume being a risk factor for revision after THA with 12 years of follow up[23]. Methodological differences, differences in populations and healthcare systems between our study and the referred studies might give rise to these conflicting findings. The age restriction allowing only patients of more than 65 years at primary surgery together with different hospital volume groups impede a comparison between the study by Manley *et al.* and Katz *et al.* and ours[18,23]. In the study by Paterson *et al.* hospitals producing less than 10 procedures per year were excluded[20]. Judge *et al.* didn't include THA from private hospitals, which in a Nordic context often are hospitals with a modest annual procedure volume[14]. Leaving out very small hospitals might have influenced the results in these two studies in favor of the remaining small volume hospitals. In an attempt to create a homogenous cohort with as little case mix as possible we looked only at THA secondary to OA. Same inclusion criteria were used in the studies by Manley *et al.*, Paterson *et al.* and Katz *et al.*[18,20,23] Associations between hospital procedure volume and risk of revision were adjusted for age and sex. In the referred studies adjustments also included co-morbidity, hospital teaching status and surgeon volume[18,20]. These data were not available in the NARA database. Consequently, residual confounding affecting an association in our study may be present.

Hospital volume was associated with the risk of revision in the cemented THA group. Already at 2 years the larger hospital volume groups were superior compared to the group with the lowest

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annual THA hospital volume. The increased risk of revision in hospitals performing less than 50 THAs per year already 2 years after primary THA indicate that not only patient related factors but also factors related to surgery and to the prosthesis brand are of importance. Hospitals with higher annual THA volume might be less affected by learning curve issues than their smaller counterparts. An important issue in performing cemented THAs is the cementing technique involving both the surgeon and the surgical nurse mixing the cement. High volume hospitals might have developed better procedures in relation to the cementing process. In the uncemented THA group we found no association between hospital THA volume and risk of revision after 1 and 2 years of follow up. After 5, 10 and 15 years of follow up we found an association between hospital volume and risk of revisions in one large hospital volume group (201–300) while RRs for the remaining three large hospital volume groups indicated a trend towards an association. Due to the small numbers of THAs and revisions in especially the largest hospital volume group after 10 and 15 years of follow up the statistical uncertainties are substantial and this issue warrants further research. Our findings are somewhat contradicting to early Norwegian findings. In a study on THAs registered in the Norwegian Arthroplasty Register from 1988 to 1996 the authors found that hospital volume didn't affect the risk of revision in cemented THAs while the risk of revision was positively associated with hospital volume in the uncemented THA group[35]. A new study population and the fact that much has happened in the treatment of THA since the study by Espehaug *et al.* might explain our slightly diverging findings in relation to the cemented THAs.

When analyzing risk of revision due to specific causes we found, that hospital THA volume clearly matters when it comes to risk of revision due to aseptic loosening. For the cemented THAs the largest hospital volume groups again had reduced RR compared to the group with the lowest annual THA volume. These significant findings and the fact that the risk estimates decreased with increase in hospital volume indicate that high volume hospitals might be less affected by learning curve issues. Even though high volume hospitals are mainly teaching hospitals, with a high share of residents these hospitals manage to reduce risk of revision due to aseptic loosening in cemented THA. This implies that not only surgical skills but also other routines and professions skills play a part in the outcome after THA. Even though the superior findings in relation to aseptic loosening relate solely to cemented THA it seems evident in economic terms to encourage the use of large THA volume hospitals. These hospitals are both on short and long term, able to reduce the number of revisions due to the far most frequent cause, aseptic loosening in cemented THA.

In the Nordic countries, like in many other countries, the annual number of THAs has steadily increased. Additionally, the amount of hospitals operating 50 THAs per year or less has decreased reflecting the general centralization that has taken place in the Nordic healthcare systems. This development seems expedient due to the observed reduced risk of revisions after primary THA in high volume hospitals.

Conclusion

This study showed a consistent and strong association between hospital procedure volume and long-term risk of revision after primary THA – primarily based on an association in the large group of cemented THAs. Hospitals operating less than 50 procedures per year had an increased risk of revision due to all causes 2, 5, 10 and 15 years after primary cemented THA. There may also be an association between hospital volume and risk of revision in uncemented THAs, however based on this study the association seems less pronounced.

Contribution of authors

ENG, ABP and TBH contributed to the conception of the study. All authors contributed to the study design. ABP, MK, LIH, OF, JK, GG and AE collected the data. All authors participated in the discussion and interpretation of the results. ENG drafted the article. All authors revised the manuscript for intellectual content and approved the final version before submission.

Competing interest statement

None of the authors have any competing interests to declare.

Conflict of interest and funding

EG was funded by the Health Research Fund of Central Denmark Region during the preparation of the study. This funding prompted no conflicts of interest.

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