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The effect of hospital-type and operating volume on the survival of hip replacements

A review of 39,505 primary total hip replacements reported to the Norwegian Arthroplasty Register, 1988–1996

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We investigated associations between the survival of total hip replacements (THRs), type of hospital and annual number of THRs per hospital. The study was based on 39,505 primary THRs reported to the Norwegian Arthroplasty Register from 45 local (n 20,756), 15 central (n 12,455) and 10 university hospitals (n 6,294) during 1988–1996. The annual number of THRs was highest at central and university hospitals, both of which are training hospitals. University hospitals were further characterized by the lowest mean annual number of THRs performed per surgeon.

For cemented THRs, with adjustment for gender, age, diagnosis, surgical procedure, and annual hospital volume, the revision rates at central and university hospitals were 0.8 (95% confidence interval: 0.67–0.95) and 1.2 (CI: 1.02–1.47) times that of local hospitals, respectively. A high annual number of cemented THRs per hospital was not associated with lower revision rates.

In uncemented THRs, survival results were similar in central and local hospitals, whereas the adjusted revision rate at university hospitals was 1.6 (CI: 1.13–2.19) times that of local hospitals. The adjusted 6.5 year revision probability was 12% in hospitals performing ≤ 10 uncemented THRs per year (n 606), 8% in hospitals performing from 18–28 operations (n 1,378) and 5% in hospitals performing > 84 operations (n 526).

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Only a few studies have considered the influence of the type of hospital on total hip replacement (THR) survival (Fowles et al. 1987, Kreder et al. 1997). On the basis of information on 39,505 primary THRs reported to the Norwegian Arthroplasty Register during 1988–1996, we have investigated possible associations between THR survival, type of hospital and annual number of THRs performed per hospital.

Patients and methods

Since September 1987, the Norwegian Arthroplasty Register has collected information on primary and revision THRs performed in Norway (Havelin et al. 1993). Any revision, defined as a surgical removal or exchange of a part of or the whole implant, is linked to data already assembled on the primary operation, using the unique person number assigned to each inhabitant of Norway. 42,413 primary THRs were performed in Norway during 1988–1996.

Hospital categories

With a population of about 4.3 million people, Norway is divided into 19 counties, which constitute the basic administrative units of somatic hospitals. Hospitals performing orthopedic surgery were classified as 45 local, 15 central and 10 university hospitals according to official Norwegian standards (Kindseth and Solstad 1995). A central or university hospital exists in 16 of the 19 counties and in each county at least one local hospital performed THR surgery.

THRs performed at two private clinics were excluded from the study, due to short follow-up and low number of operations (n 240). Two hospitals specializing in orthopedic surgery were categorized as university and central hospital, respectively.

In order to obtain homogeneous data, THRs with incomplete information on use of cemented or uncemented prostheses (n 647) and THRs with hybrid cement use (n 2,021) were excluded from the study. The present study thus included 39,505 operations performed during the period from 1988 through 1996 at

70 different departments in 64 hospitals. An orthopedic department was considered as the observational unit in the statistical analyses. However, departments were for simplicity referred to as hospitals.

Annual hospital volume and annual surgeon volume

Annual hospital volume was defined as the total number of THRs performed per hospital each year. In analyses performed among cemented and uncemented THRs, the annual hospital volume referred to the annual number of cemented and uncemented THRs, respectively.

Information on individual surgeons is not reported to the Norwegian Arthroplasty Register. A separate questionnaire was therefore sent to each hospital, inquiring about the number of consultant surgeons and residents in training (registrars) who performed hip arthroplasty during 1996, and about the annual average of surgeons for the period 1988 through 1995. Thus, annual surgeon volume was not known on an individual basis, but was calculated for each hospital as the ratio between the annual number of THRs and the number of orthopedic surgeons (consultants and residents in training).

Statistics

In analyses of THR survival, the endpoint was defined as revision for any cause. The survival times for THRs were censored if the patient had died or the study had ended without revision of the implant. Information on deaths before February 1, 1997 was received from the Central Bureau of Statistics, Oslo, Norway. Kaplan-Meier survival curves for hospital types were calculated for all THRs and for subgroups performed with or without cement. Two-sided log-rank tests (Mantel 1966) were performed to investigate whether any differences in survivorship among hospital types were statistically significant.

Further investigations based on Kaplan-Meier survival analyses and multiple Cox regression analyses were performed separately for cemented and uncemented THRs. In the Cox regression analyses, annual volume of cemented (≤35, 36–52, 53–81, 82–132, 133–213, >213) and uncemented (≤10, 11–17, 18–28, 29–54, 55–84, >84) THRs were categorized, based on the 10th, 25th, 50th, 75th and 90th percentiles, respectively. In addition to gender, age (≤65, 66–75, >75 among cemented THRs; ≤45, 46–60, >60 among uncemented THRs) and primary diagnosis (arthrosis, rheumatoid arthritis, sequelae after hip fracture, sequelae after dysplasia without dislocation, others), covariates with detailed information on the surgical procedure were included in the regression models. Information on type of cement (high viscosity, low viscosity, Boneloc, combinations), prosthesis brand (Charnley, Exeter, Titan, Spectron/ITH, other) and use of antibiotic prophylaxis (systemic antibiotics combined with antibiotic-loaded cement, systemic antibiotics only, antibiotics in cement only, no antibiotics) were included in analyses based on cemented THRs, while type of prosthesis ('poor' design, 'good' design) and use of systemic antibiotic prophylaxis (yes, no) were included in analyses based on uncemented THRs. Uncemented THRs with circumferentially hydroxyapatite-coated, porous-coated or rough sandblasted stems, and hydroxyapatite-coated or hemispherically porous-coated cups, were classified as THRs with 'good' design based on the performance during 6 years of follow-up (Havelin et al. 1995a,b). Analyses were also performed on subgroups of cemented THRs performed with or without high viscosity cement, and of uncemented THRs with 'poor' and 'good' design properties. In the Cox models, risk factors with more than two levels were represented with indicator variables to avoid assumptions of linear relationships.

The relationship between annual hospital volume and revision rate was also studied on the basis of generalized additive models for survival data (Hastie and Tibshirani 1990). The generalized additive model and the Cox regression model differ in the representation of continuous covariates. In a generalized additive model, the effect of a continuous covariate on the log revision rate may be represented by a smooth and possibly nonlinear function, whereas in a Cox model a continuous covariate must be categorized to detect nonlinear or threshold effects on survival. Analyses based on generalized additive models thus provided graphic displays of the relationship between annual volume per hospital and the log revision rate. Each curve was 'centered', so that the average contribution to the log revision rate was zero (Hastie et al. 1992). Separate analyses were performed for cemented and uncemented THRs, with adjustment for potential confounding by hospital type, gender, age, diagnosis, and factors related to the surgical procedure, as given above. The statistical software Gamfit, written by Trevor Hastie (Stanford University, CA) and Robert Tibshirani (University of Toronto, Ontario, Canada), was applied in these analyses. Gamfit is available in the General archive of StatLib (Carnegie Mellon University, Pittsburgh, PA).

The statistical software S-PLUS (MathSoft Inc. 1997) and SPSS (SPSS Inc. 1993) were otherwise used for the statistical analyses.

Table 1. Patient and procedure characteristics by type of hospital among 39,505 primary THRs performed in Norway, 1988–1996

Characteristics	Hospital type: Local	Central	University
No. THRs	20,756	12,455	6,294
Median no. consultant surgeons	3	5	7
Median no. residents in training	0	3	4
Median THRs/hospital/year	84	130	122
Median THRs/surgeon/year [a]	27	18	11
Median operating time, min.	90	95	110
Patient characteristics in %			
Primary arthrosis	74	68	56
Men	30	31	31
≤65 years	21	32	41
66–75 years	43	39	34
Procedure characteristics in %			
Cemented	92	87	64
Uncemented	8.5	13	36
Uncemented 'poor' design	4.7	3.1	8.7
Uncemented in patients ≤ 65 yrs	34	39	72

[a] Median value of annual no. of THRs / no. surgeons participating in THR surgery (consultants and residents) at each hospital.

Results

Of 39,505 primary THRs performed in Norway at 70 hospitals, 53% were performed at 45 local hospitals, 32% at 15 central hospitals and 16% at 10 university hospitals. The annual number of THRs was highest at central and university hospitals, both of which were training hospitals. The annual number of THRs/number of surgeons was lowest at university hospitals and highest at local hospitals (Table 1).

The proportion of young patients and patients with other diagnoses than primary coxarthrosis was highest at university hospitals and lowest at local hospitals. Among THRs in patients aged 65 or less at the primary operation, 34% were uncemented at local hospitals, 39% at central hospitals, and 72% at university hospitals. The longest operating times were found at university hospitals and the shortest at lLocal hospitals (Table 1). Among cemented THRs, 77% were performed with a Charnley prosthesis at university hospitals, compared to 50% at central hospitals. Among uncemented THRs, prostheses with a 'poor' design were commonest at local hospitals (Table 2).

The poorest survival was observed among THRs performed at university hospitals and the best among THRs performed at central hospitals (Figure 1), with unadjusted revision rates 1.5 ($p < 0.001$) and 0.9 ($p = 0.01$) times that of local hospitals. Differences among hospital types were less pronounced among cemented and uncemented THRs, respectively (Figure 1). How-

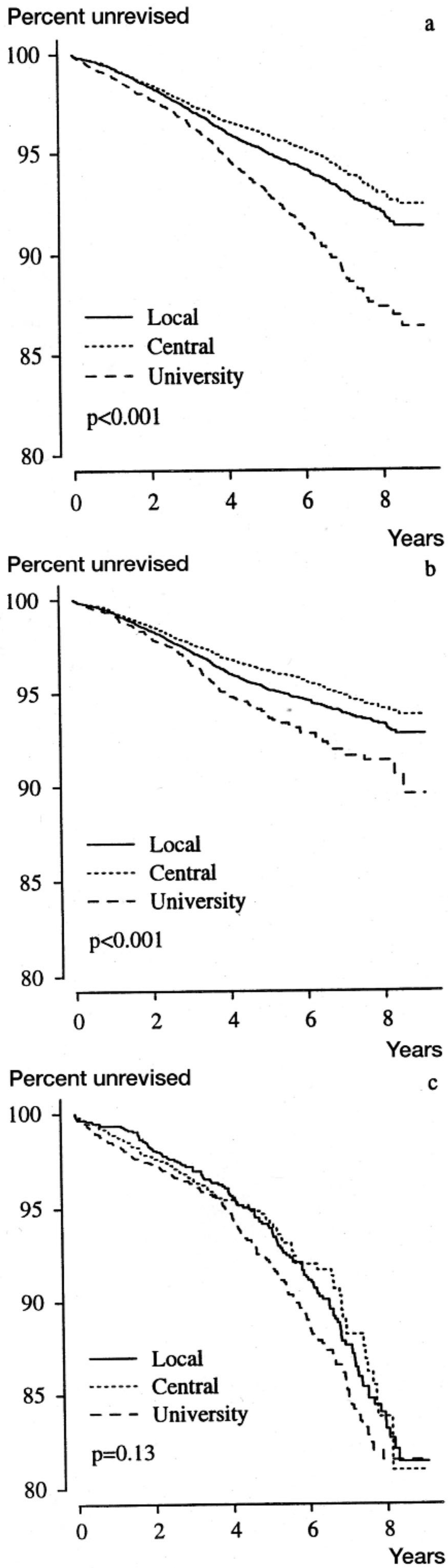

Figure 1. Unadjusted survival curves with strata defined by the three hospital types among primary THRs performed in Norway, 1988–1996. The p-value refers to the log rank test of homogeneity in survivorship among hospital types. Cemented and uncemented THRs (a), cemented THRs (b) and uncemented THRs (c),

Table 2. Patient and procedure characteristics by type of hospital among 33,917 cemented and 5,588 uncemented primary THRs performed in Norway, 1988–1996

	Cemented THRs			Uncemented THRs		
Characteristics	Local	Central	University	Local	Central	University
No. THRs	18,990	10,873	4,054	1,766	1,582	2,240
Median THRs/hospital/year	67	123	113	19	23	45
Median THRs/surgeon/year [a]	23	16	8	4	4	4
Median operating time, min.	90	100	119	80	90	100
Patient characteristics in %						
Primary coxarthrosis	75	72	69	55	42	34
Men	29	29	27	39	40	38
≤65 years, cemented	16	22	18			
66–75 years, cemented	46	44	46			
≤45 years, uncemented				14	22	27
46–60 years, uncemented				51	66	44
Procedure characteristics in %						
Antib.: systemic only	53	46	36	99	95	97
Antib.: systemic and in cement	43	48	58			
High viscosity cement	88	94	92			
Charnley, cemented	60	50	77			
Poor design, uncemented				55	24	24

[a] Median value of annual no. of THRs/no. surgeons participating in THR surgery (consultants and residents) at each hospital.

Table 3. Cox regression revision rate ratios (RR) calculated with any revision as endpoint among cemented primary THRs performed in Norway, 1988–1996

		Unadjusted		Adjusted [a]			
Covariates	n [b]	RR	P	% rev. [c]	RR	95% CI	P
Hospital type							
Local	18,690	1		4.3	1		
Central	10,757	0.8	0.005	3.4	0.8	0.67–0.95	0.01
University	3,991	1.3	0.001	5.3	1.2	1.02–1.47	0.03
THRs/hospital/year [d]							
≤35	3,360	1		3.8	1		
36–52	5,105	1.2	0.17	3.8	1.0	0.82–1.32	0.76
53–81	8,327	1.1	0.36	3.9	1.0	0.79–1.25	0.95
82–132	8,327	1.0	0.97	3.9	1.1	0.85–1.35	0.54
133–213	5,078	1.5	<0.001	4.6	1.2	0.98–1.59	0.08
>213	3,241	1.1	0.64	5.1	1.3	0.97–1.82	0.08

[a] The model included hospital type, hospital volume, gender, age, diagnosis, prosthesis brand, cement type and antibiotic prophylaxis use.
[b] Numbers were reduced due to missing values in the covariates.
[c] Percent revised after 6.5 years.
[d] Cutpoints at the 10th, 25th, 50th, 75th and 90th percentiles.

ever, compared with local and central hospitals, the adjusted revision rate was higher at university hospitals, whether or not the prosthesis was cemented (Tables 3 and 4). Adjustment for gender, age and diagnosis had no influence on the results. Similar findings were observed within subgroups of cemented THRs performed with or without high viscosity cement. Comparing university and local hospitals, the adjusted revision rate ratio (RR) was higher among uncemented prosthesis types associated with 'poor' short-term survival (RR = 1.8, p = 0.004) than among uncemented prostheses of 'good' design (RR = 1.2, p = 0.56).

Cox regression analyses showed that a high annual number of cemented THRs per hospital was not associated with lower revision rates (Table 3), whereas the revision rate decreased with an increasing number of uncemented THRs (Table 4). The adjusted 6.5-year revision rate among uncemented THRs was 12% at hospitals performing 10 or less uncemented THRs per year, 8% if performing from 18–28 operations and 5% if performing more than 84 operations (Table 4).

Table 4. Cox regression revision rate ratios (RR) calculated with any revision as endpoint among uncemented primary THRs performed in Norway, 1988–1996

		Unadjusted		Adjusted [a]			
Covariates	n [b]	RR	P	% rev. [c]	RR	95% CI	P
Hospital type							
Local	1,737	1		6.5	1		
Central	1,568	1.0	0.99	6.5	1.1	0.80–1.51	0.55
University	2,217	1.2	0.07	10.9	1.6	1.13–2.19	0.01
THRs/hospital/year [d]							
≤10	606	1		12.2	1		
11–17	885	0.6	0.001	9.1	0.7	0.48–0.94	0.02
18–28	1,378	0.6	<0.001	8.1	0.6	0.42–0.85	0.004
29–54	1,286	0.6	<0.001	7.5	0.6	0.41–0.84	0.004
55–84	841	0.5	<0.001	9.8	0.6	0.38–0.97	0.04
> 84	526	0.5	<0.001	5.0	0.4	0.28–0.66	<0.001

[a] The model included hospital type, hospital volume, gender, age, diagnosis, prosthesis type and antibiotic prophylaxis use.
[b] Numbers were reduced due to missing values in the covariates.
[c] Percent revised after 6.5 years.
[d] Cutpoints at the 10th, 25th, 50th, 75th and 90th percentiles.

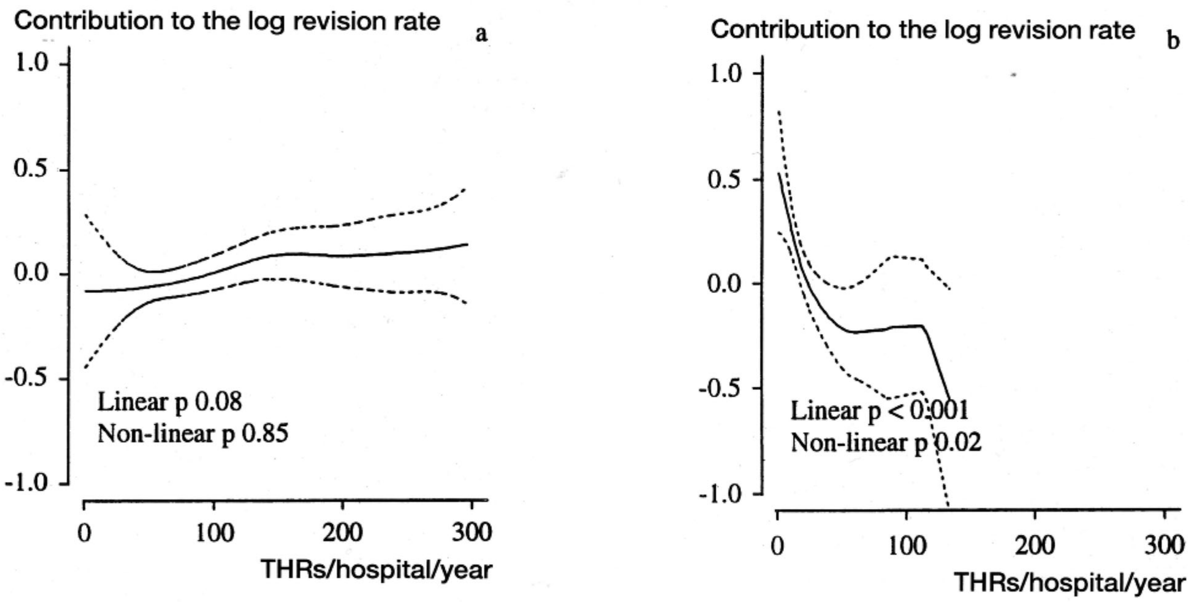

Figure 2. Graphic display of the relationship between annual number of THRs performed at each hospital and the log revision rate among THRs performed in Norway, 1988–1996. The curves, presented with 95% confidence intervals, were based on generalized additive proportional hazards models, with adjustment for hospital type, gender, age, diagnosis, and surgical procedure. The linear p refers to a linear trend test and the non-linear p to a test of nonlinearity in effects. Cemented THRs (a) and uncemented THRs (b).

Additional adjustment for the number of orthopedic surgeons at each hospital gave only negligible differences in estimates.

Findings based on Cox regression analyses were corroborated by results based on the generalized additive modeling of survival data (Figure 2). The annual number of cemented THRs per hospital was much higher than for uncemented THRs. However, there was no indication of increased revision rates, even for very low annual volumes of cemented THRs per hospital (Figure 2).

Discussion

Our study showed that primary THRs performed at university hospitals were revised more often than THRs at central and local hospitals. Although higher proportions of young patients and patients with diagnoses other than coxarthrosis were operated on at university hospitals, these differences could not explain the increased revision rate at university hospitals. The high revision rate at university hospitals was in part associated with a more frequent use of uncemented designs commonly associated with poor outcome

(Havelin et al. 1995a, b). However, comparing local and central hospitals, revision rates were also consistently higher at university hospitals within subgroups of THRs performed with or without cement, and after adjustment for gender, age, diagnosis, and procedure-related risk factors such as cement type, prosthesis type, and antibiotic prophylaxis regimen (Havelin et al. 1994, 1995c, Espehaug et al. 1995, Espehaug et al. 1997a, Furnes et al. 1997), and annual number of THRs per hospital. Adjustment for possible confounding by patient characteristics may not have been complete, as other factors associated with increased revision rates, including alcohol intake, steroid medication and diabetes (Espehaug et al. 1997b), were not investigated in our study. The longer operating times at university hospitals may indicate that more difficult procedures were performed, but may also be related to the lower annual operating volume per surgeon. Furthermore, university hospitals were training hospitals, but so also were central hospitals, in which the revision rate was lower than in university hospitals.

Few studies have focused on revision rate as outcome in relation to the number of THRs per hospital (Fowles et al. 1987, Kreder et al. 1997). Only Fowles et al. (1987) reported an association between low operating volume and an increased risk of revision. However, information regarding the definition of low volume and whether the influence of other risk factors had been controlled for was not provided by this study. Our findings indicated a 'learning curve' on the hospital level for uncemented THRs, where the highest revision rate was observed in hospitals performing 10 or less uncemented THRs a year. A similar finding was not observed among cemented THRs, suggesting that practice is more important in relation to uncemented THRs. The general experience with uncemented prostheses may also be poorer than for cemented prostheses.

As the name of the surgeon is not reported to the Norwegian Arthroplasty Register, annual surgeon volume was calculated for each hospital as the ratio between the number of THRs performed and the number of orthopedic surgeons, thus assuming a uniform distribution of operations among surgeons participating in THR surgery. In university hospitals, we observed a high number of THRs per hospital and a low annual number of THRs per surgeon. The lowest revision rates were found in local and central hospitals, where the number of THRs per surgeon was high, irrespective of the total number of THRs per hospital. The experience of the surgeon has been associated with THR outcome (Buchholz et al. 1985, Courtois et al. 1985), and a low number of THRs per surgeon has been identified as a risk factor for revision (Fowles et al. 1987, Kreder et al. 1997). An annual rate of at least 25 THRs has been suggested to maintain technical skills (Fowles et al. 1987), whereas the median operating volume per surgeon was 11 THRs in university hospitals, 18 in central hospitals and 27 in local hospitals. Kreder et al. (1997) reported that surgeons performing less than 2 operations a year had a revision rate twice as high as surgeons performing 2 or more operations.

In the present study, both central and university hospitals were training hospitals with large annual volumes of THRs, but with clinically important differences in outcome. Possible explanations of the poorer results in university hospitals may involve the probable centralization of high-risk patients with additional medical diseases, along with the low number of operations per orthopedic surgeon.

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