A commentary by Anne R. Bass, MD, is linked to the online version of this article at jbjs.org.

Ten-Year Trends in Medical Complications Following 540,623 Primary Total Hip Replacements from a National Database

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Background: More than 75,000 total hip replacements were performed in England and Wales in 2014, and this figure is predicted to increase. Trends in mortality and complications following total hip replacement from 2005 to 2014 were evaluated to quantify risk and to identify "at-risk" groups to better inform recommendations for patient care.

Methods: Our primary analysis estimated 90-day inpatient mortality following total hip replacement using Hospital Episode Statistics data from 2005 to 2014. Secondary analyses explored 30-day rates of lower respiratory tract infection, renal failure, myocardial infarction, pulmonary embolism, deep-vein thrombosis, cerebrovascular accident, and *Clostridium difficile*. Hierarchical logistic regression was used to estimate population averages, adjusting for time and prognostic covariates.

Results: From January 2005 to July 2014, a total of 540,623 total hip replacements were reported. The 90-day mortality rate dropped steadily, from 0.60% in 2005 to 0.15% in 2014. Reported postoperative complications (with the exception of lower respiratory tract infection and renal failure) reduced year-on-year, despite a steady rise in the average Charlson Comorbidity Index score. The 30-day rate of lower respiratory tract infection and renal failure increased from 0.54% to 0.84% and 0.21% to 1.09%, respectively. The risk of mortality was significantly higher for those who developed a lower respiratory tract infection (odds ratio [OR] = 42.3) or renal failure (OR = 36.5) than for those who developed pulmonary embolism (OR = 10.9) or deep-vein thrombosis (OR = 2.6).

Conclusions: Despite a population with increasing levels of comorbidity, indicators of quality of care improved from 2005 to 2014, with the exception of the rates of lower respiratory tract infection and renal failure. Postoperative care should focus on reducing the risk of lower respiratory tract infection and renal failure, both of which increased and were strongly associated with mortality. Moreover, they appeared to occur in identifiable high-risk groups; modifications to routine care should be considered for these patients.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Total hip replacement is a highly successful and cost-effective intervention, with >75,000 procedures performed in England and Wales in 2014[1-3]. Comprehensive data from the National Joint Registry for England, Wales, and Northern Ireland (NJR) have permitted detailed understanding of how and why the performance of hip replacement surgery varies and the influences on surgical and patient outcomes of a range of surgical, patient, and prosthesis characteristics[4]. The publication of surgeon-level data was introduced in England and Wales in June 2013 to increase

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TABLE I Demographics of Patients Who Underwent Total Hip Replacement (THR) from January 2005 to July 2014*

	2005			2014				Overall	
		%	95% CI		%	95% CI	P Value		%
No. of THRs	34,643			40,758				540,623	
Sex									
No. of female	21,359	61.7	61.1-62.1	24,469	60.0	59.6-60.6	<0.0001	328,941	60.8
No. of male	13,249	38.2	37.9-38.9	16,282	39.9	39.4-40.4	<0.0001	211,280	39.1
No. unknown	35	0.1		7	0.01			402	0.1
Mean age *(yr)*									
Overall	69.0		68.8-69.7	68.0		67.9-68.1	<0.0001	68.4	
Female	69.8		69.7-69.9	68.8		68.6-68.9	<0.0001	69.2	
Male	67.6		67.4-67.8	66.7		66.6-66.9	<0.0001	67.1	
No. with comorbidities									
No comorbidities	21,445	61.9	61.4-62.4	19,338	47.4	47.0-47.9	<0.0001	283,428	52.4
Hypertension	10,727	31.0	30.5-31.5	18,374	45.1	44.6-45.6	<0.0001	216,283	40.0
IHD	1,854	5.4	5.1-5.6	2,868	7.0	6.8-7.3	<0.0001	35,593	6.6
AF	1,423	4.1	3.9-4.3	2,392	5.9	5.6-6.1	<0.0001	28,288	5.2
IDDM	156	0.5	0.4-0.5	133	0.3	0.3-0.4	0.006	2,132	0.4
NIDDM	1,995	5.8	5.5-6.0	3,704	9.1	8.8-9.4	<0.0001	42,970	7.9
COPD	691	2.0	1.8-2.1	1,737	4.3	4.1-4.5	<0.0001	17,349	3.2

*CI = confidence interval, IHD = ischemic heart disease, AF = atrial fibrillation, IDDM = insulin-dependent diabetes mellitus, NIDDM = non-insulin-dependent diabetes mellitus, and COPD = chronic obstructive pulmonary disease.

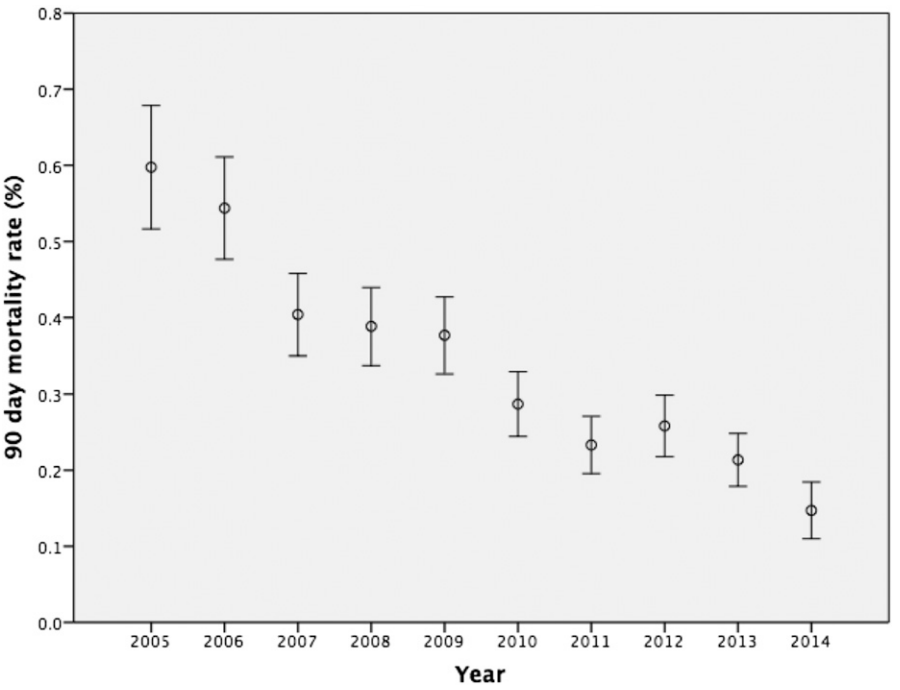

Fig. 1

Annual 90-day inpatient mortality rate following primary total hip replacement among NHS patients in England. The error bars indicate the 95% confidence interval.

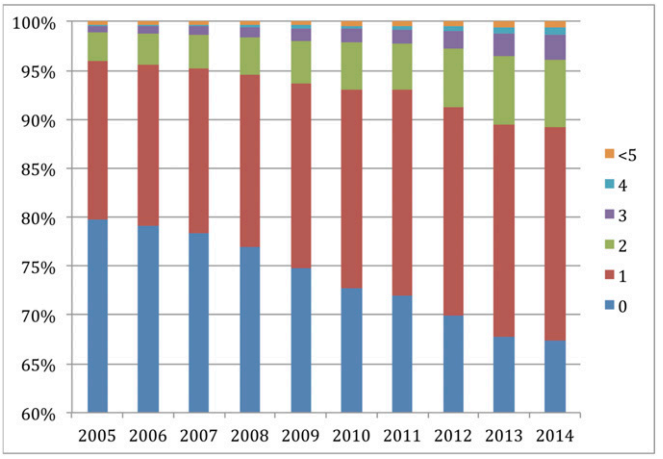

Fig. 2
Annual distribution of Charlson Comorbidity Index scores.

transparency regarding surgical outcomes[5]. The information published includes surgeon volume and 90-day mortality. At the national level, the associated 90-day mortality rate after a hip replacement fell consistently in recent years, from 0.56% in 2003 to 0.29% in 2011[6]. Major complications have been noted to occur in 2% of procedures[7], with the majority occurring in the first 4 postoperative days[8].

Experiencing a major complication is associated with a higher mortality rate[9,10]. However, low rates of complications make it difficult to determine risk factors from case-series reports. The Hospital Episode Statistics (HES) data warehouse provides access to inpatient data on all joint replacements performed in the English National Health Service (NHS). Novel methods of analyzing these data can provide clinicians with new insights into the best ways to treat individual patients, by tailoring perioperative and postoperative care. This has the potential to reduce morbidity and mortality, reduce health-care costs, and maximize the benefit of total hip replacement. It should also allow improved "patient-specific" informed consent and provide evidence to redirect valuable health-care resources to more appropriate "at-risk" groups.

To our knowledge, there are currently no validated risk tools for reliably estimating complications after total hip replacement. The American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) surgical risk calculator[11] was developed in 2013 from >1.4 million cases but fails to provide accurate risk estimations for lower-limb joint replacement[12]. Attempts to make arthroplasty-specific tools have objectively been underpowered and require external validation[13]. By analyzing complication rates over time, we aimed with this study to provide current risk estimations on the basis of a large cohort of patients, to inform recommendations for the care of high-risk groups.

Materials and Methods

Our research was limited to the secondary use of non-identifiable information previously collected in the course of normal care and was therefore exempt from formal ethical approval.

Study Design and Data

This was a retrospective cohort study. We used HES data to assess rates, trends, and determinants of complications among all patients who underwent NHS-funded primary total hip replacement in England from January 2005 to July 2014. For patients who underwent >1 joint replacement during the study period, each replacement was treated as a discrete event.

HES data in the form of the OPCS-4 (Office of Population Censuses and Surveys Classification of Surgical Operations and Procedures, 4th Revision) and ICD-10 (International Statistical Classification of Diseases and Related Health Problems, 10th Revision) codes were used to establish rates of myocardial infarction, cerebrovascular accident, lower respiratory tract infection, renal failure, deep-vein thrombosis, pulmonary embolism, and *Clostridium difficile* infection within 30 days (see Appendix). All-cause inpatient 90-day mortality was also extracted. Age, sex, comorbidities, and Charlson Comorbidity Index (CCI) score[14] were recorded for each patient. The CCI predicts patient 1-year mortality.

Statistical Methods

The analytic framework was hypothesis-generating rather than formal hypothesis-testing, and thus, a p value of <0.05 was considered significant for findings meriting further investigation, without adjustment for multiple comparisons.

The primary analysis estimated 90-day inpatient mortality following hip replacement. Event rates over time were explored using a hierarchical logistic model, with hospital trust as a random effect, and estimating population average estimates, averaging trust-level random effects, and providing robust standard errors. Serial autocorrelation was explored and excluded from the final models as insignificant to the estimation. Model covariates explored at the patient level were age, sex, and history of hypertension, atrial fibrillation, ischemic heart disease, hyperthyroidism, hypothyroidism, insulin-dependent diabetes mellitus, non-insulin-dependent diabetes mellitus, circulatory disease, chronic obstructive pulmonary disease (COPD), dementia, Alzheimer disease, and osteoporosis. Secondary analyses similarly explored 30-day rates of other events: myocardial infarction, cerebrovascular accident, lower respiratory tract infection, renal failure, deep-vein thrombosis, pulmonary embolism, and *C. difficile*.

Analyses were performed using STATA/IC (version 13.1; StataCorp); proportions were estimated from models using reported odds and odds ratios (ORs). Model estimates were used to plot fitted lines by population and subpopulation.

Patient Involvement

No patients were involved in setting the research question or the outcome measures. In tandem with this project, a qualitative study will explore the patient experience of complications as well as the consenting process. The end goal is to

TABLE II Associated Risk of 90-Day Mortality, by Complication, Following Total Hip Replacement from January 2005 to July 2014*

	2005, N = 34,643			2014, N = 40,758			Overall, N = 540,623		
		90-Day Mortality			90-Day Mortality			90-Day Mortality	
	No. (%)	No. (%)†	OR (95% CI)	No. (%)	No. (%)†	OR (95% CI)	No. (%)	No. (%)†	OR (95% CI)
MI	167 (0.48)	38 (22.8)	59.8 (40.4-88.5)	75 (0.18)	7 (9.33)	78.9 (34.6-179.8)	1,906 (0.35)	273 (14.3)	59.2 (51.6-67.9)
PE	268 (0.77)	18 (6.7)	13.0 (7.9-21.5)	162 (0.40)	2 (1.23)	8.7 (2.1-36.1)	2,967 (0.55)	99 (3.34)	10.9 (8.9-13.4)
DVT	400 (1.15)	5 (1.3)	2.1 (0.9-5.2)	116 (0.28)	0	—	3,376 (0.62)	29 (0.86)	2.6 (1.8-3.8)
CVA	2 (0.01)	0	—	6 (0.01)	2 (33.3)	350.8 (63-1,952.9)	61 (0.01)	18 (29.5)	127.3 (73-221.1)
RF	73 (0.21)	15 (20.5)	46.3 (25.8-83.1)	443 (1.09)	15 (3.39)	31.4 (17.4-56.7)	3,242 (0.60)	299 (9.22)	36.5 (32.1-41.6)
LRTI	188 (0.54)	34 (18.1)	43.8 (29.3-65.3)	342 (0.84)	14 (4.09)	37.5 (20.4-68.8)	3,907 (0.72)	389 (9.96)	42.3 (37.6-47.5)
C. difficile	57 (0.16)	12 (21.1)	47.0 (24.5-90.2)	8 (0.02)	1 (12.5)	98.5 (11.9-813.3)	510 (0.09)	68 (13.3)	48.1 (37.1-62.4)

*OR = odds ratio, CI = confidence interval, MI = myocardial infarction, PE = pulmonary embolism, DVT = deep-vein thrombosis, CVA = cerebrovascular accident, RF = renal failure, LRTI = lower respiratory tract infection, and *C. difficile* = *Clostridium difficile*. †The percentage is of the total number of hip replacements with the indicated complication at that time period.

enhance shared decision-making, the patient experience, and outcomes.

Results

From January 2005 to July 2014, a total of 540,623 total hip replacements (474,128 patients) were recorded in HES. Of those hip replacements, 328,941 (60.8%) were performed in female patients, with a mean age of 69.2 years, and 211,280 (39.1%) were performed in male patients, with a mean age of 67.1 years. The frequency of recorded comorbidities is shown in Table I.

The 90-day mortality rate consistently dropped annually, from 0.60% in 2005 to 0.15% in 2014 ($p < 0.0001$) (Fig. 1). This was despite a progressive increase in the levels of comorbidity, as shown by the CCI score distribution (Fig. 2).

Postoperative complications, with the exception of lower respiratory tract infection and renal failure, decreased annually (Table II). The 30-day rate of myocardial infarction decreased from 0.48% to 0.18% ($p < 0.0001$); pulmonary embolism, from 0.77% to 0.40% ($p < 0.0001$); deep-vein thrombosis, from 1.15% to 0.28% ($p < 0.0001$); and *C. difficile,* from 0.16% to 0.02% ($p < 0.0001$). The 30-day rate of lower respiratory tract infection and renal failure increased from 0.54% to 0.84% ($p < 0.0001$) and 0.21% to 1.09% ($p < 0.0001$), respectively, and were the most frequent complications in 2014. The associated risk of 90-day inpatient mortality was significantly higher for those who developed a lower respiratory tract infection (OR = 42.3; 95% confidence interval [CI] = 37.6 to 47.5; $p < 0.0001$) or renal failure (OR = 36.5; 95% CI = 32.1 to 41.6; $p < 0.0001$) than for those who developed pulmonary embolism (OR =10.9; 95% CI = 8.9 to 13.4; $p < 0.0001$) or deep-vein thrombosis (OR = 2.6; 95% CI = 1.8 to 3.8; $p < 0.0001$). The overall risks of mortality associated with these conditions all decreased over the study period, with the exception of myocardial infarction and *C. difficile*.

After adjusting for age, sex, and comorbidities, we noted an association between 90-day inpatient mortality and preexisting ischemic heart disease (OR = 2.3; 95% CI = 2.1 to 2.7; $p < 0.001$), atrial fibrillation (OR = 2.5; 95% CI = 2.2 to 2.8; $p < 0.001$), insulin-dependent diabetes mellitus (OR = 2.8; 95% CI = 1.7 to 4.5; $p < 0.001$), non-insulin-dependent diabetes mellitus (OR = 1.4; 95% CI = 1.2 to 1.6; $p < 0.001$), and COPD (OR = 2.8; 95% CI = 2.4 to 3.3; $p < 0.001$), but not hypertension (OR = 0.9; 95% CI = 0.9 to 1.0; $p = 0.265$) (Table III).

The risk of experiencing postoperative myocardial infarction was associated with preexisting ischemic heart disease (OR = 4.6; 95% CI = 4.0 to 5.2; $p < 0.001$), atrial fibrillation (OR = 2.1; 95% CI = 1.9 to 2.4; $p < 0.001$), and insulin-dependent diabetes mellitus (OR = 2.3; 95% CI = 1.4 to 3.7; $p < 0.001$). The risk of developing a postoperative lower respiratory tract infection was associated with a previous diagnosis of COPD (OR = 3.1; 95% CI = 2.8 to 3.5; $p < 0.001$) or atrial fibrillation (OR = 2.4; 95% CI = 2.1 to 2.6; $p < 0.001$). The risk of experiencing postoperative renal failure was strongly associated with preexisting insulin-dependent diabetes mellitus (OR = 5.0; 95% CI = 3.7 to 6.8; $p < 0.001$) and, to a lesser extent, atrial fibrillation (OR = 2.1; 95% CI = 1.9 to 2.3; $p < 0.001$), non-insulin-dependent diabetes mellitus (OR = 2.2; 95% CI = 2.0 to 2.4; $p < 0.001$), and COPD (OR = 2.0; 95% CI = 1.7 to 2.2; $p < 0.001$).

TABLE III Odds Ratios (and 95% CIs) for Complications and 90-Day Mortality, by Comorbidity*

Comorbidity		Complication							90-Day Mortality
		MI	PE	DVT	CVA	RF	LRTI	*C. difficile*	
HTN	2005	1.2 (0.8-1.6)	0.9 (0.7-1.1)	1.0 (0.8-1.3)	—	2.0 (1.3-3.3)†	1.2 (0.9-1.7)	0.8 (0.4-1.4)	1.0 (0.8-1.4)
	2014	1.2 (0.7-2.0)	1.0 (0.7-1.4)	0.7 (0.5-1.1)	0.7 (0.1-3.6)	1.6 (1.3-1.9)‡	0.9 (0.7-1.2)	0.7 (0.2-3.2)	1.5 (0.8-2.6)
	Overall	1.2 (1.1-1.3)‡	1.0 (0.9-1.1)	1.0 (0.9-1.1)	0.7 (0.4-1.3)	1.3 (1.2-1.4)‡	1.0 (0.9-1.1)	0.8 (0.7-1.0)	0.9 (0.9-1.0)
IHD	2005	5.9 (4.3-8.3)‡	1.6 (1.0-2.4)†	0.8 (0.5-1.2)	—	1.2 (0.6-2.5)	2.4 (1.6-3.5)‡	3.0 (1.4-6.4)†	2.7 (1.9-3.8)‡
	2014	9.0 (5.6-14)‡	1.2 (0.7-2.0)	0.9 (0.4-1.9)	3.2 (0.5-19)	1.5 (1.1-1.9)†	1.7 (1.3-2.3)‡	0.7 (0.1-9.1)	2.1 (1.1-3.8)†
	Overall	4.6 (4.0-5.2)‡	1.3 (1.2-1.5)‡	1.1 (0.9-1.2)	1.1 (0.5-2.5)	1.6 (1.5-1.8)‡	1.6 (1.4-1.7)‡	1.4 (1.0-1.8)†	2.3 (2.1-2.7)‡
AF	2005	3.2 (2.2-4.7)‡	1.7 (1.1-2.7)†	0.8 (0.5-1.4)	—	2.7 (1.5-5.1)†	3.1 (2.1-4.6)‡	2.0 (0.9-4.5)	2.5 (1.7-3.6)‡
	2014	2.3 (1.3-4.0)†	1.1 (0.6-1.9)	1.7 (0.9-3.3)	4.6 (0.8-27)	2.1 (1.6-2.6)‡	2.5 (1.9-3.4)‡	1.0 (0.1-12.0)	2.6 (1.4-4.7)†
	Overall	2.1 (1.9-2.4)‡	1.4 (1.3-1.6)‡	1.0 (0.9-1.2)	1.9 (0.8-4.2)	2.1 (1.9-2.3)‡	2.4 (2.1-2.6)‡	2.0 (1.6-2.6)‡	2.5 (2.2-2.8)‡
IDDM	2005	1.2 (0.2-8.5)	2.3 (0.7-7.3)	—	—	3.0 (0.4-22)	—	—	—
	2014	6.8 (1.6-29)†	1.8 (0.3-13)	—	—	5.9 (2.8-12)‡	0.8 (0.1-5.8)	40 (3.3-494)‡	4.1 (0.5-31)
	Overall	2.3 (1.4-3.7)‡	0.8 (0.4-1.4)	0.7 (0.4-1.4)	1.0 (1.0-1.0)	5.0 (3.7-6.8)‡	1.6 (1.1-2.5)†	1.0 (0.2-4.0)	2.8 (1.7-4.5)‡
NIDDM	2005	1.8 (1.2-2.9)†	0.5 (0.2-0.9)†	1.0 (0.6-1.5)	—	2.3 (1.3-4.4)†	1.7 (1.1-2.7)‡	0.5 (0.1-2.1)	0.7 (0.4-1.3)
	2014	1.2 (0.6-2.2)	1.2 (0.7-1.9)	1.3 (0.7-2.4)	—	2.4 (1.9-3.0)‡	1.4 (1.0-1.8)†	3.5 (0.6-19)	1.0 (0.5-2.1)
	Overall	1.7 (1.5-1.9)‡	0.8 (0.7-1.0)†	1.0 (0.8-1.1)	1.1 (0.5-2.6)	2.2 (2.0-2.4)‡	1.3 (1.2-1.4)‡	1.2 (0.9-1.6)	1.4 (1.2-1.6)‡
COPD	2005	0.8 (0.3-2.1)	1.6 (0.9-3.1)	1.0 (0.5-2.0)	—	3.2 (1.4-7.6)†	2.9 (1.6-5.1)‡	—	2.3 (1.3-4.1)†
	2014	1.1 (0.5-2.5)	2.3 (1.4-3.9)†	1.6 (0.8-3.2)	—	1.8 (1.3-2.4)‡	3.5 (2.6-4.7)‡	—	3.0 (1.5-6.1)†
	Overall	1.4 (1.1-1.6)†	1.5 (1.3-1.8)‡	1.4 (1.2-1.6)‡	1.2 (0.4-3.6)	2.0 (1.7-2.2)‡	3.1 (2.8-3.5)‡	2.3 (1.7-3.2)‡	2.8 (2.4-3.3)‡

*After adjustment for age, sex, and other comorbidities. CI = confidence interval, MI = myocardial infarction, PE = pulmonary embolism, DVT = deep-vein thrombosis, CVA = cerebrovascular accident, RF = renal failure, LRTI = lower respiratory tract infection, *C. difficile* = *Clostridium difficile,* HTN = hypertension, IHD = ischemic heart disease, AF = atrial fibrillation, IDDM = insulin-dependent diabetes mellitus, NIDDM = non-insulin-dependent diabetes mellitus, and COPD = chronic obstructive pulmonary disease. †$P < 0.05$. ‡$P < 0.001$.

Discussion

Despite a population with increasing levels of comorbidity, indicators of quality of care improved from 2005 to 2014, with the exception of the rates of lower respiratory tract infection and renal failure. Perioperative complication and mortality rates are key concerns for patients, anesthetists, and surgeons. Elective hip arthroplasty is consistently reported to have a very low perioperative mortality rate[15-22] and low medical complication rates[8,22]. However, Dimick et al. concluded that the minimum caseload necessary to detect a doubling of the mortality rate for hip replacement surgery was 2,668 cases[23]. In order to reliably identify changes in mortality or medical complications, single institutions need to collect data over large time intervals to accumulate data that demonstrate significance[24]. The average number of total hip replacements performed per unit was 363 in England in 2013, inferring that >7 years of data are required to attain the estimation of Dimick et al. This carries the risk of averaging results over decades despite notable improvements in the quality of care over time. In contrast, large regional or national databases in Europe and the U.S. provide more statistically robust data, allow earlier detection of potential problems, and eliminate single institution-based selection bias[8,25-27].

The aim of this study was to determine up-to-date medical complication and mortality rates, identifying "at-risk" groups following hip arthroplasty in England. Our national data analysis showed an annual reduction in the 90-day mortality rate after total hip replacement consistent with, and extending, a recent NJR analysis[6]. It is generally accepted that the risk of mortality is highest immediately following surgery, but the overall 90-day mortality rate was lower than that previously reported for age, sex and comorbidity-matched patients who did not undergo total hip replacement[27,28].

The publication of surgeon-level data introduced in 2013 has sharpened focus on complications after surgery, with the intention of increasing transparency and, ultimately, reducing mortality[5]. The consistent drop in mortality after total hip replacement during the period of study implies successive advances in surgical practice and medical care, irrespective of the publication of surgeon-level outcome data.

Although our HES data did not include privately funded patients, we know that 88% of hip replacements in England in 2014 were performed within the NHS[3]. Evidence suggests that private institutions tend to "cherry-pick" the healthier patients (limited critical care provision in the private sector precludes patients of higher surgical risk), and we would therefore expect that our data would over-represent the complication and mortality rates compared with data including those of patients in the private sector[29]. Our current study also included NHS patients at private units and independent treatment centers.

A potential limitation of our study was the quality of HES data. The database relies on the precision of trained but non-medical staff inputting data using the ICD-10 and OPCS-4 coding systems. As these patients were planned admissions for surgery, it was assumed that none of the complications occurred prior to total hip replacement. HES is an internationally unique resource, the accuracy of which is perceived to be improving since the introduction of payment by results in 2004. As these data are used for billing, each trust is externally audited. A recent audit of 50 trusts found an average error rate of 7.0%[30].

HES data also have the limitation of the recording of only inpatient deaths. The data set captures readmission with subsequent death but does not record deaths occurring outside the hospital. Therefore, the absolute mortality rate is underestimated. Our mortality trend is, however, consistent with that of a previous national study that used Office of National Statistics data to identify all deaths[6].

For patients who underwent >1 joint replacement during the 10-year study period, each replacement was treated as a discrete event. Having a previous hip replacement could impact future risk and, therefore, overall complication estimates. However, it was not possible to exclude all patients who had had a hip replacement prior to 2005 or any other surgical procedure during the period of study.

The CCI[14] is a widely used tool and has demonstrated excellent predictive validity[31]. However, this index tends to underestimate comorbidity because it is limited to 19 conditions and has poor interconditional weighting, but its simplicity in design makes its adaptation feasible[31]. The apparent increase in annual CCI scores may be a result of improved coding; however, one would also expect a similar increase in codes for complications such as deep-vein thrombosis and pulmonary embolism. The improved diagnosis of many conditions such as hypertension and non-insulin-dependent diabetes mellitus is known to have increased with time[32].

HES data do not include specific cause of death. A previous report[15] found that the main cause of death following total hip replacement was cardiovascular-related. Our study found lower respiratory tract infection to be the complication most commonly associated with death following joint replacement. The lower respiratory tract infection rate was 0.72% (3,907 procedures), with mortality reported following 389 (9.96%) of those procedures. Renal failure was the second-most common complication associated with mortality. The renal failure rate was 0.60%, with mortality reported following 299 (9.22%) of 3,242 procedures. However, renal failure is more likely to be simultaneous with other complications and, therefore, may not have been the main cause of death; HES data do not classify severity of kidney injury. The myocardial infarction rate in our study was 0.35%, with mortality reported following 273 (14.3%) of 1,906 procedures. This did not, however, take into consideration the possibility of silent myocardial infarction[33].

Pulmonary embolism following arthroplasty remains a much-debated topic, particularly with regard to choices of thromboprophylaxis[34-36]. In scrutinizing the records of all patients following primary hip replacement in 1990 in a single U.K. health region, Fender et al. found a fatal pulmonary embolism rate of 0.19% (4 of 2,090 patients) and determined that a study would require 67,000 randomized patients to be significant if fatal pulmonary embolism were to be used as the end point[37]. Wroblewski et al. showed 122 pulmonary embolism-related deaths in 18,104 Charnley arthroplasties (0.67%) from 1970 to 1986[38], and Lie et al. found a fatal pulmonary embolism rate of 0.92% between 1987 and 1995 (45,767 patients)[16]. Our data revealed a pulmonary embolism rate of 0.55%, and a fatal pulmonary embolism rate of only 0.018% (99 total hip replacements). The consistent reduction in both pulmonary embolism and deep-vein thrombosis could be attributed to adherence to National Institute of Clinical Excellence (NICE) guidance on venous thromboembolism (VTE) prophylaxis. However, the adherence to and effect of VTE guidance has previously been questioned[34] and the observed reductions in deep-vein thrombosis and pulmonary embolism rates may be the result of enhanced recovery protocols, including the switch from general to spinal anesthesia and early postoperative mobilization. The implementation of such protocols has been shown to reduce short-term complications and mortality[39].

Three times as many patients died following lower respiratory tract infection as compared with pulmonary embolism, yet no routine prophylaxis is provided to reduce the risk of respiratory-related complications. Preoperative respiratory physiotherapy has been associated with a reduction in

postoperative pulmonary complications in cardiac and major abdominal surgery[40]. Its role in lower-limb joint arthroplasty, to our knowledge, has not been described, but it could be adopted for at-risk patients, such as those with COPD.

All indicators of quality of care improved from 2005 to 2014, with the exception of the rates of lower respiratory tract infection and renal failure. We hypothesize that the increased rate of renal failure may be as a result of the national drive to reduce *C. difficile* by promoting a change in surgical prophylaxis from cephalosporins to gentamicin, while acknowledging that nationwide practice remains varied[41]. Gentamicin is associated with an increased rate of renal failure even when used as a single-dose prophylaxis[42]. The rate of *C. difficile* fell, from 0.16% to 0.02% (in line with *C. difficile* rates generally in England)[43], but potentially at the expense of increasing renal failure. For at-risk patients (notably, patients with diabetes), alternatives to gentamicin could be considered for surgical prophylaxis. The findings of a recent large randomized trial suggest that statins may increase rates of renal failure after surgery[44]. While acknowledging their potential benefit in reducing the risk of ischemia in patients undergoing cardiac surgery, we should consider stopping the use of statins in total hip replacement patients at high risk of renal failure.

Total joint replacement in the English NHS has a very low risk of mortality and postoperative complications: 3% of procedures being followed by a medical complication. Despite a population with progressively more comorbidities, the rates of complications, with the exception of those of lower respiratory tract infection and renal failure, improved from 2005 to 2014. To date, the drive for quality has focused on avoiding deep-vein thrombosis and pulmonary embolism. This should now focus on chest infections and renal failure, which were more common, increased, and very strongly associated with death. Identifying at-risk groups for additional prophylactic measures could reduce these complications.

Appendix

eA A table showing the ICD-10 and OPCS-4 codes used in our analysis is available with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/E621). ■

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